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INDOOR CLIMATE IN AIR-SUPPORTED STRUCTURE

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DESCRIPTION

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Indoor Climate in Air-Supported Structure

Abstract

The air supported structure is quite modern type of building for sport purposes. The main advantages of this structure are low cost and multigrade function. Such benefits allow to consider this type of sport facility as a perspective and modern decision for sport industry in northern countries. But what about quality of indoor climate in air domes? Does the condition of indoor environment allow to use these facilities for performing of workouts and even the sport competition?

The main aim of thesis is to research the basic parameters of indoor climate in air domes, to estimate the quality of indoor climate in such type of sport facilities. For that purpose the air dome was investigated and the measurements of basic indoor climate parameters were carried out. These basic parameters are air temperature, relative humidity, pressure level, carbon dioxide level and mean air velocity. Also the same investigation was done in two other sport facilities: sport hall and gym. The getting data of measurements were compared to each others. All results of measurements in three sport facilities were compared finally with requirements for indoor climate quality in few regulation documents. All data were presents in tables and results of monitoring illustrated in graphs.

The result of researching the indoor climate quality shows that the air supported structure meets the requirements in regulation documents. The air supported structure may be considered as an alternative substitution of ordinary sport facilities.

Subject headings, (keywords)
indoor climate, air-supported structure, sport halls, air dome, gym, measurements, air temperature, relative humidity, pmv, ppd, air velocity, air pressure, carbon dioxide, monitoring, quality, instruments, devices

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1 INTRODUCTION

Sport is one of the essential components of our lives. If you want to be healthy, to have a strong immune system and just to have a good appearance, you should include some sport activities in your life. It doesn’t matter to set a world record or to trying to reach something serious. It’s enough for keeping your health if you just start to make some sport activities during 0.5 - 1 hours per day. In fact, after such sport activities you should start to feel yourself better, to feel charged of energy and to feel new forces in your body. This is due to the fact that our body, after an active movement, gets more oxygen and the heart starts to work in intensive mode, which increases blood circulation, accelerate metabolism, which will positively impact not only on health but also on your overall appearance.

As you can see, sports and physical work increase oxygen consumption of working muscles, therefore the activity of the respiratory system of human also increases. This suggests that breathing and the air which we breathe are very important in sport. Because of that, it is better to play sports in parks, stadiums or in sport halls, where the air is cleaner. If, for example, you start to run along the road which polluted by exhaust gases, it doesn't help you, but on the contrary, will harm your health.

So, the indoor climate of space where occur some sport activities play a significant role for health of sportsmen. Outdoors it’s not too difficult to choose the right place for sport activities; you just should to avoid places where are some possible source of air pollution presented. As was written above, you should choose such places for sport activities like parks, stadiums and so on. But indoors, the air quality mostly doesn’t depend on you. Very often sports events are held in special sports halls, especially in countries with cold climates. In such type of buildings the indoor air quality is designed by HVAC engineers, however, maintenance of the technical system and the building as a whole play an important role.

Nowadays there are many different types of buildings which are related with sport activity. The type of such buildings and some features depend on kind of sports. For example, it may be swimming pool, gym, ordinary sport hall for basketball or volleyball, riding hall, a huge covered stadium for football games or for athletics and so on.

The buildings for sporting events developed and improved annually in accordance with new regulations and requirements. Sometimes innovations in the field of construction of sports facilities appear due to the requirement for adaptation some kind of sports in countries with northern cold climate. Such as football, athletics, tennis - sports that require large areas and good weather conditions.

One of the latest such developments is air-supported structure. Also there is another name of this structure: air dome. It's a good solution for northern countries which have cold climate. The design of such structures does not require any supporting pillars inside and it's a big advantage. Building costs of air domes are quite low due to simple system of construction. The main advantage of such construction for countries with cold climate is to possibility to create suitable indoor climate under the dome, to create certain temperature of air. More information about air-supported structure is presented in the theoretical part of this thesis.

As was written above, quality of indoor air is very important factor for sportsmen's health. Also, it's very interesting and non-ordinary structure because the air is main support of it. The main idea is that the internal pressure should be equal or exceeds external pressure. It means that under the dome of such structure there is overpressure air. So, we have a very interesting point of this discussion about sport's structure and indoor climate – the point where meet two main ideas: "indoor air is very important for sportsmen's health" and "air-supported structures contain overpressure air inside". Do these two basic ideas about good indoor air quality and overpressure air inside one air dome meet the requirements for indoor climate in sport halls or in another structure which is related with sport activities such as air-supported structure?

It's very interesting questions for me also because during the last year I played football very often in such kind of structure like air dome. Actually a felt myself a little bit strange every time at the first 15 minutes of the game. I felt that the breathing is difficult, that my body requires more oxygen than I can breathe. Other players also felt the same discomfort at the beginning of the game, at the first minutes of active movements. But every time after another 15 minutes everything started to be ok again and we continued to play further without any strange feelings.

The health of sportsmen significantly depends on the indoor air quality and in general health is very important. Also the air-supported structures may be quite advanced in the future, because the operation costs of it are not too expensive in comparison with ordinary sport halls or covered stadium. So, does air-supported structure provide necessary condition with good indoor air quality for sport activities? Is it harmful for sportsmen’s health to train or play in such type of sport’s structure? It’s quite actual question and I decide to find answer on it in my bachelor thesis. I decide to investigate indoor air in air-supported structure.

At the first part of bachelor thesis there is theoretical background, description of standards and guidelines about requirements for indoor climate, description of research objects, methods of measurements. Also there is a detailed description of air-supported structure. At the second part of thesis are presented results of measurements, evaluation of experimental data, analyze of measurements and some calculations. The final part of this work contains discussion which based on data from measurements and conclusion. Conclusion includes some solutions for new possible ways to improve quality of indoor air in sport halls and in air-supported structure. Also this bachelor thesis contains detailed description of results of measurements in three different sports facilities.

To achieve the objectives, I have used different methods. For instance, I had to get information about quality of indoor climate in different sports facilities. The methods of investigation of indoor climate in air-supported structure and other two sports facilities include measurements of different characteristics of air and some characteristics of indoor climate generally: pressure level inside the sport buildings, temperature of air, air flows at different points of the measured objects, the content of carbon dioxide in air, humidity of the air and some others.

One of the methods of investigation of indoor climate in sports facilities is comparison of experimental data with results of measurements of other sports facilities. For comparison of different characteristics in air-supported structure I chose two another sports facilities. One of them is ordinary sport hall in D-building of MUAS which is intended for sport games like a volleyball, mini-football, basketball and floor ball. Another sport facility is gym in U-building of MUAS. Gym contains different equipments for training and also there are small room for martial arts.

One of the methods which was also used in this bachelor thesis is calculation different values of, for example, content of carbon dioxide and handling of experimental data. The different sources and literature, official regulations and guidelines for construction engineering field from different countries were used for creating of theoretical part of this thesis.

2 AIMS

The main aim of this research work is to define whether the indoor climate of air-supported structures meets the requirements and regulations for indoor climate in structure for sports activities. If it doesn't meet the requirement, the second aim is to develop ways of solving this problem, to decide which type of ventilation should be utilized or which equipment in ventilation system should be installed.

Also one of the aims is to compare indoor air climate of air-supported structure with two other sports facilities: gym and ordinary sport hall. For this purpose, there is a target to measure quality of indoor air in gym and sport hall. Finally, the third aim is to estimate perspective of air-supported structure in the future based on results of measurements. For example, to find answer on such question like: is it a suitable place for performing large and serious sport competition or not, is the indoor climate in air domes not too harmful for health of sportsmen.

As we can see, when we reach all aims and get appropriate results we can answer on different important questions about indoor climate in buildings where different sport events are arranged. It must be very useful to know which place is suitable for sport competition and also this information can help us to improve quality of indoor climate in sports facilities. Due to good quality of indoor air, sportsmen could achieve better results and also sporting events could become more spectacular. So, the aims of this bachelor thesis are quite relevant.

3 THEORETICAL BACKGROUND

Theoretical part of this thesis is presented by discussion about quality of indoor climate, description of main parameters of air and devices for measurements. Also there are discussions about significant role of quality of indoor climate for sportsmen's health. After that there is a description of several regulations and guidelines from few countries about indoor climate in sports facilities. Finally, this chapter contains comparison of all standards which are used to evaluate the quality of the indoor climate into three investigated sports facilities.

3.1 Indoor climate quality

There are many factors which are included in the general concept of indoor environment. All of them can be divided into four groups: building design, acoustics, lighting and indoor air quality and climate. These four groups contain many different specific parameters which have influence on human comfort. But majority of factors that significantly affect on the human comfort are part of the group which called "indoor air quality and climate". Because of that, this thesis investigates such problem as quality of indoor climate and air. /1, p. 6./

The concept of indoor environment quality is divided into three directions which are quite closely related with each other. Due to these directions, the indoor climate were carefully described and represented. The first direction is indoor air. The condition of indoor air is usually expressed by contents of various groups of air pollutants. For instance, it may be volatile organic compounds (VOCs), particles and gases, microbes and odours. The second group which can provide information about some physical characteristics of indoor climate is thermal environment. It is usually described by values of air temperature, air movement, surface temperature, distribution and moisture content. In fact, air humidity level (moisture) is also related with the first direction. The third direction is cleanliness. There are three main factors which effect on total cleanliness of indoor spaces: ventilation, air handling equipment and space cleaning. As you can see, there are many parameters of indoor environment which belong to different groups and directions in whole hierarchy of indoor climate. But some of them have significant impact on the human health and comfort then the others. For investigation of indoor environment in sport halls were chosen several critical parameters. Such as air temperature, air movement (draught), relative and absolute humidity of air, pressure level inside the indoor space and pressure difference between outside and inside environment and carbon dioxide level. /1, p. 6./

Indoor climate is a complex of physical factors of indoor environment which influence on the heat exchange of the human body. The physical climate factors include air temperature, relative and absolute humidity of air, air velocity, temperature of building envelope, temperature gradient in the vertical and horizontal directions into the indoor space, the intensity of the thermal radiation from the inner surfaces. Almost all of these physical factors are describe the thermal climate. Thermal comfort depends on activity and clothing also. /2, p. 16-18./

The comfort conditions of indoor climate are combination of different parameters which provide a suitable thermal state of the human body with a minimum stress for mechanisms of thermoregulation of human body. The main such mechanisms are sweating and shivering. In practice, optimal thermal climate provides comfort for not more than 80% of people in the same room. /2, p. 91-92./

Vital functions of each person are accompanied by continuous release of heat to the environment. The amount of heat loss depends on the level of physical activity which is expressed by energy consumption for certain climate conditions. For normal physiological processes in the human body it is very important when the heat released by the human body is fully discharged to the environment. Violation of the heat balance can lead to overheating or overcooling of the body and, as a consequence, to fatigue, loss of consciousness and decrease level of productivity. The temperature fluctuations cause changes in muscle tone, disease of peripheral vascular, sweat gland activity, high heat production. /2, p. 94-95./

The human endurance against the temperature fluctuation and their thermal sensations are highly dependent on humidity and velocity of air. The higher relative humidity cause less evaporation of sweat per unit of time and the faster overheating of the body. The high relative humidity combined with high temperatures cause especially negative effect on the thermal state of the person. For instance, almost all of heat released into environment while the evaporation of sweat when the temperature is about 30 °C. The sweat does not evaporate even if the humidity is increasing and dripping from the surface of the skin. So, the pouring sweat appear which is exhausting the body and do not provide the necessary heat exchange. /2, p. 97-99./

Indoor climate is formed due to influence from the external environment, due to some features of construction of the building and due to design of the heating, ventilation and air conditioning systems also. Usually, the air which is penetrating from the streets into the premises is polluted. For instance, the air which penetrates from the neighbouring apartments and stairwells are contaminated by some gas impurities. Inside the room, the air is distributed unevenly. There can form a zone with a high content of harmful impurities. Also, in multi-storey buildings there is quite big air pressure difference between outdoor environment and indoor environment. As a result, there is a high possibility of gas and bacteriological contamination of air on the upper floors and the risk of cooling on the lower floors, combined with the increasing risk of radon contamination. /2, p. 113-115./

It is well known that the air we breathe has a great impact on our health and performance. Nowadays people spend a lot of time at indoors spaces. It means that the air we breathe almost always passes through the air handling units and ducts of the building. Daily consumption of air by human varies from 20 to 30 kg. /3./

The quality of indoor air is related with content of aerosols and gases, temperature, and humidity. In premises with people, air quality is determined by its ability to maintain the health and performance of people. The most important factor of indoor air is purity. Air pollutants - particles, gases and vapours can reduce human performance and cause harm for human health. /4./

The requirements for quality of indoor climate often depend on the types of indoor activities which are performed in certain types of buildings. For instance, humidity and temperature of indoor air in museums should be kept on a certain level because otherwise it can have harmful influence on some exhibition such as pictures or sculptures. Other example is hospitals. There are operational rooms or laboratories which need clean indoor environment and have strict requirements for indoor air. Also some kinds of manufactures such as producing of microelectronic or optical components require special condition of indoor environment. /2, p. 15-16./

Indoor climate of sports facilities also requires special attention. Because the main purpose of sports facilities is to perform different trainings and sport competitions. It means that there are non ordinary indoor activities. Sportsmen usually train very intensively and perform work by muscles, the rate of movements is quite high and thus human body produce extra heat to indoor spaces. Such non ordinary type of indoor activity needs special conditions because poor quality of indoor environment effect on well-being of sportsmen and their health. How does it affect on health of sportsmen will be described in the next paragraph.

3.2 Effect of indoor climate on health and performance of sportsmen

Human performance depends on the purity and freshness of the air. Fresh air in the room is the foundation of good health. As was written above, the respiratory system of sportsmen is more sensitive to indoor air and more requiring to quality of indoor climate. Effect of air on the health of athletes depends on the content of oxygen in it. The oxygen content is one of the main characteristic of air. Sportsmen need oxygen to increase physical activity, accelerate muscle recovery after sports loads.

So, the good air quality is very important especially for people who are involved in sport active work. It’s also so because when we start to make some sport exercises or just to make an active movement the consumption of air by our lungs increases in 10-15 times /5/. At the same time, when the consumption of air by human increases, the production of carbon dioxide also increases. These two processes depend on each other quite greatly. On the other hand, the production of carbon dioxide depends on the physical activity level of the person. So, we get quite interesting situation when oxygen consumption by human depends on physical activity level of person which also affected on the production of carbon dioxide by human, and the level of excreted carbon dioxide influence on the oxygen content into the close indoor spaces. Also both oxygen and carbon dioxide content in the indoor air depend on the carbon dioxide content in outdoor air which is intake by air handled unit. Oxygen content in the indoor air, oxygen consumption, carbon dioxide production and physical activity level are interconnected and all of these processes occur dependently of each other. Connection between all of these processes and their mutual work are quite clearly presented by graphical way at the figure 1 below.

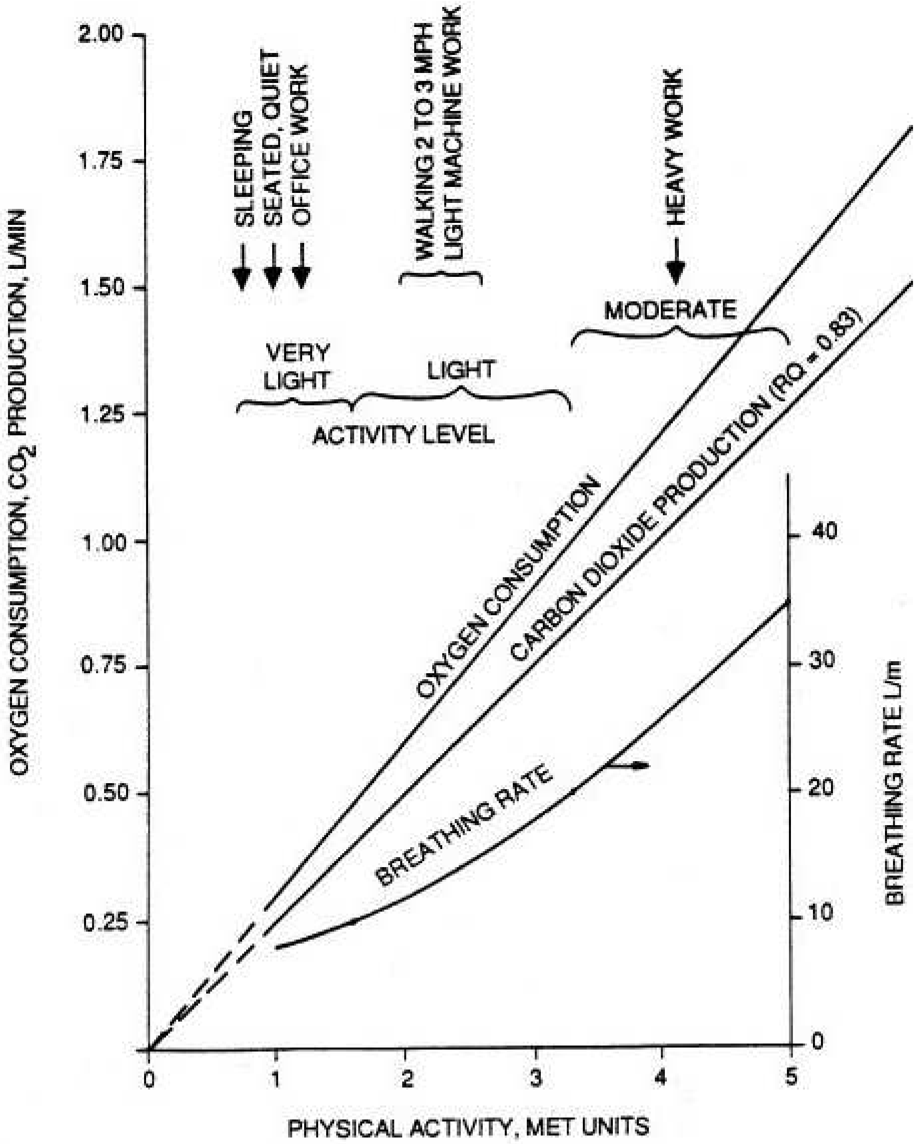

FIGURE 1. Relation between oxygen consumption, CO2 production and physical activity level of human /6, p.32/.

The left vertical axis at the figure 1 shows us the oxygen consumption and carbon dioxide production level by human body and it's expressed in units as litres per minute. The right vertical axis shows the breathing rate of human also in units as litres per minute. Single horizontal axis expresses physical activity level of person. From the figure 1 we can see the relation between physical activity level of person and production of carbon dioxide and some other relation. For instance, if the person is seatting in the office and his physical activity level is quite low, then the consumption of oxygen decrease to the low level as well as carbon dioxide production and breathing rate of that person. Otherwise, if the person performs heavy work as a doing some sports activity, then the oxygen consumption and accordingly the carbon dioxide production level and breathing rate of that person are start to increase in several times.

In our case, we consider the quality of indoor climate in the sports facilities. In such places are often occur heavy sports activities. We, like HVAC-engineers and designers, should take into account that the carbon dioxide level very strongly influence on the total quality of indoor environment and at the health and performance of sportsmen, thus, we must control it and keep it at the certain suitable level. Many national regulations and guidelines for indoor climate give the separate requirements for limit of car-bon dioxide level inside the indoor space of sports facilities.

Usually, physical activity level is expressed in units as met. At the figure 1, the horizontal axis marked by units met and it shows us the level of physical activity of the per-son. Metabolic rate shows the certain amount of energy which expended by human body while some physical work is performed. Each type of physical activity requires the certain amount of energy for perform it. For example, such function as walking with velocity about 5 kilometres per hour is requires approximately 354 W and this value equals to 3.4 met. One met is equal to 105 W and this amount of energy is needed while person is seated peacefully. The average surface area of human body is 1.77 square meters. Due to 1 met is approximately equal to 58 W per one square meter of human body. So, in another words, metabolic rate expressed the amount of energy which release from one square meter of human body. The example of relations between physical activity level and metabolic rate is presented in source /2, p. 93/ of this thesis and also in the table 1 below. /2, p. 92-94./

TABLE 1. Physical activity and metabolic rates /2, p. 93/

Physical Activity	Metabolic rate	
	met	W/m^2
Sleeping	0.8	48
Seated, relaxed	1.0	58
Office work	1.0 – 1.2	58 – 71
Standing, medium activity	2.0	116
Carrying a load, 10 kg	2.3	136
Walking, 8 km/h	5.8	342

Thus, in our case, physical activity level of sportsmen influence on the level of carbon dioxide production, which, in its turn, is affect on the total quality of indoor environment. In other words, HVAC-designers should consider the carbon dioxide content in the indoor air because it can significantly affect on the performance and heath of sportsmen.

Thermal climate also is very important part of indoor environment. The condition of thermal climate could effect on the performance and heath of sportsmen. As was written above, metabolic rate is expressed by the energy production of human body. To be precise, human body generates the heat by way of performing some mechanical work /2, p. 93/. Almost all heat which was generated is released to the environment. The amount of released heat is almost always in balance with heat which was generated. Sometimes there are occurring some deviations in thermal balance. A good thermal climate means that the person is satisfied with different thermal parameters. When it's so, the person feels the thermal comfort. It's mean that the thermal balance of his body is laid into the certain suitable range. /2, p. 91-92./

There are many factors which affect on the thermal balance of the human body. To keep the thermal balance at the suitable level is very important especially for sportsmen because thermal balance influence on the total performance and health of sportsmen.

There are some key factors which can effect on the performance and health of sportsmen. Such as air temperature, relative air velocity, indoor air pressure level, metabolic rate and insulation in clothing. Thus, all of these parameters of environment should be considered. /2, p. 91-93./

As you can see, thermal climate plays significant role in the design of suitable indoor environment for sports facilities. Body of sportsman produce quite big volume of heat during the sport activities and sportsman can start to feel discomfort especially if the temperature of indoor air is not suitable. In case of sport activity indoor air temperature should be lower than in usual case. It's so because metabolic rate of sportsmen also is at unusual high level and it add some amount of energy into thermal balance of sportsmen. Also the air movement should be at the certain level because if the velocity of air is too high it can create a draught which, in its turn, can cause discomfort for sportsmen. The relation between draught, air temperature and air velocity is presented by graphical way at the figure 2 below. /7, p. 31./

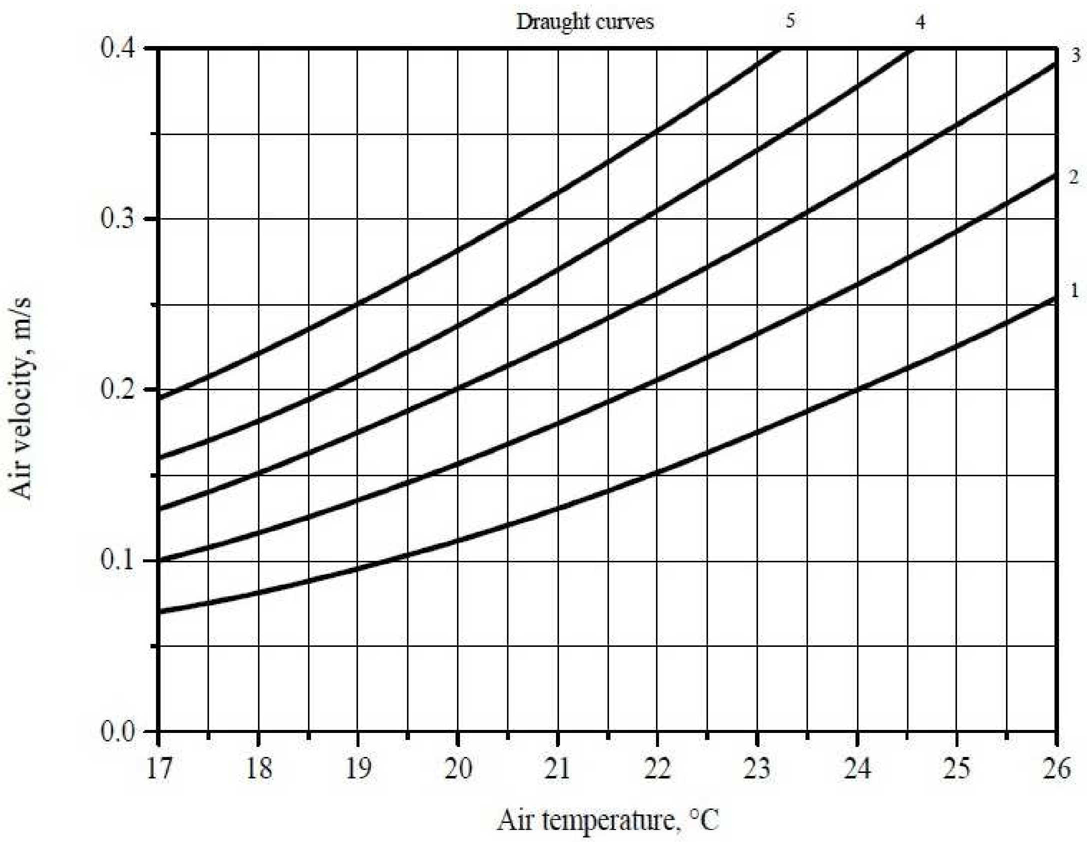

FIGURE 2. Relation between draught, air temperature and air velocity /7, p. 31/

The draught can have significant influence on health of sportsman especially in case where the indoor air temperature is not at the suitable level and sportsman can start to sweat or vice versa he can start to shiver. It can cause discomfort and even a cause disease of sportsman. Because of it many national regulations and guidelines for indoor climate give the separate requirements for limit of air velocity inside the indoor space of sports facilities.

So, the quality of indoor climate influences on the performance and health of the sportsmen. It's very important to control the indoor environment and keep it at the suitable level. HVAC-designers play significant role for forming of good indoor climate with high quality in the sports facilities. It also affected at the productivity of athletes. Qualitative indoor climate allow the sportsmen achieve their best results and set a new records.

3.3 Regulations and guidelines

Significant role of indoor air quality in sport buildings is obvious. The control of characteristics of indoor climate should be performed. But, how to know which parameters of indoor air quality are suitable? With which standards and guidelines we should compare received experimental data which describe condition of indoor environment into three investigated sports facilities?

The requirements for indoor climate of sport halls are presented in different regulations and guidelines. Usually, each country has its own standards or guidelines for indoor climate in sport halls. Also, there are some international organizations which published regulations and standards for HVAC field of design. The most famous such organisations are ASHRAE and REHVA. The abbreviation of first organisation means "American Society of Heating, Refrigerating and Air-Conditioning Engineers". It's an American organization which published some regulations and guidelines for HVAC field of design and for indoor environment of different spaces including those. The abbreviation of second organization means "Representatives of European Heating and Ventilating Associations" but it's an old name which was changed nowadays into "Federation of European Heating, Ventilating and Air-conditioning Associations".

But, in spite of this, the old name was saved and still utilized. So, REHVA is a European organization which includes 26 members – different European countries. This organization also published some regulations and guidelines for HVAC field of design. So, as could be seen, there are many regulations, guidelines and standards for HVAC design field of engineering but all of them differ between in the stringency and type of requirements for HVAC design. /8./

In this thesis the measurements were performed in three sports facilities which are located in a city in Finland – Mikkeli. So, it means that the comparison of measured data should be done with Finnish national standards. But also, there are presented description and review of regulation or guidelines which are utilized in other countries. It's useful to compare the standards with the purpose to define the best requirements for each parameter of indoor climate and to compare experimental data with both Finnish standards and new improved standards.

The investigated objects are sports hall, gym and air dome. Each sports facility requires the certain parameters for indoor environment. In fact, the requirements from standards are almost the same but sometimes there are some differences between values of parameters. Into this chapter described the indoor climate parameters from related standards for sports facilities in general and if it possible for each of sports facility separately. It depends on the type and information capacity of standard or regulation. Also the most interesting, for this investigation work, requirements or limits which are presented into standards are air temperature, air velocities, carbon dioxide content level, relative or absolute humidity, and available indoor pressure level if it is stipulated in the standard.

For investigation and comparison were chosen few standards. Some of them are from Russia, USA and Finland. Some guidelines and standards of European Union were chosen also.

3.3.1 Finnish regulations

All investigated sports facilities are located in Mikkeli, Finland. So, it means that the Finnish regulations should be considered first of all. Into this research work two Finnish regulations for indoor environment were chosen. First regulation was from National Building Code of Finland (NBC). It's a compulsory guideline like a law which should be met by the constructers. NBC was published by the Ministry of the Environment on the indoor Climate and ventilation of buildings in Finland. It has been develop by Housing and Building Department of Finland. NBC include seven chapters into its structure. Each chapter contain requirements for certain field of construction and building design. NBC also include suitable requirements for indoor environment which are a part of division named as Hepac and energy management. It's marked by letter D. This division contains seven subchapters. One of them is named as "Indoor Climate and Ventilation of Buildings" and marked as D2. /7./

The D2 contains different requirements for condition of indoor environment. In this thesis investigated D2 which was published in 2003. The D2 give us information about general principles of ventilation systems, about indoor climate in different types of buildings and its different rooms and some information about energy performance of ventilation systems. Also this standard contain various definitions related with ventilation systems, certain values for air temperature, air velocities, air quality, air flow rates into supply and exhaust parts of ventilation, requirements for acoustic and lightning conditions and so on.

According to D2 indoor temperature for gymnastic hall is 18 °C. This value should be kept in sports facilities during the heating season. Also D2 contains data about limit for carbon dioxide level: "The maximum permissible indoor air carbon dioxide content in usual weather conditions and during occupancy is usually 2,160 mg/m3 (1,200 ppm)." /7, p. 9/. Some recommendations about indoor air humidity level are also presented into D2. Humidity content of indoor air should meet the purpose of certain type of premises. Also humidity level of indoor air shouldn't be too high during long period of time, and it shouldn't concentrate somewhere on the structures, or surfaces, or into ventilation ducts. The level of humidity content in air shouldn't provide suitable conditions for growth of mold, microbes or micro-organisms. Also the optional high value of air temperature should be avoided during the heating season for purpose to prevent high air humidity level.

D2 include some limits for air velocity inside the sports premises (indoor spaces). According to the table 3 in D2 standard the upper limit for indoor air velocity in huge sports hall is 0.3 m/s. The maximum available air velocities for fitness halls and small gym halls are 0.25 m/s. Both of limits for air velocity should be met during winter and summer. /7, p. 35./

The detailed information about all requirements for indoor environment of sports facilities are presented in the table 2 below.

TABLE 2. Requirements for indoor climate of sports facilities from D2 /7/

Sports Facility	Parameters of Indoor Climate			
	Air temp., °C	CO_2 level, ppm	Air Velocity, m/s	Pressure Level, kPa
Air Dome	18	≤ 1200	≤ 0.3	101.3
Sports Hall	18	≤ 1200	≤ 0.3	101.3
Gym	18	≤ 1200	≤ 0.25	101.3

Also into this thesis was reviewed a Finnish guideline for indoor climate. The name of this guideline is “Classification of Indoor Environment“. It was published by the Finnish Society of Indoor Air Quality and Climate (FSIAQC) in 1995 but in this work were considered latest version of regulation which was published in 2008. The guideline contains requirement for indoor air quality. In fact the requirements which given in this regulation are voluntary. The document contains different recommendations for indoor climate which can help the HVAC designers to improve indoor air quality. The main feature of this regulation is that it contains system of classification of indoor environment which has three categories: S1, S2 and S3. The first one means “Individual indoor environment” and it’s the best category of indoor climate. If conditions of indoor air quality meet the requirements from S1 category, it means that the indoor climate is on the quite high level of quality. The S2 category is named as “Good indoor environment”. It corresponds to middle level quality of indoor air. The last one, S3 category is named as “Satisfactory indoor environment” and it corresponds to ordinary indoor air quality level. /9, p. 4-5./

The classification of indoor environment contains target values for thermal environment according to each of three categories. The guideline hasn’t got separate requirements for certain types of premises such as sports facilities or residential spaces. So, into this part of chapter presented information about suitable parameters for indoor climate of some room or premises. In the guideline the target values for air temperature are expressed by operative temperature. Operative temperature takes into account both radiation and convection /10/. According to the document the indoor air temperature during the winter should be 21.5 °C for S1, S2 categories and 21.0 °C for S3. The allowed deviation is ± 0.5 °C for S1 and ± 1.0 °C for S2 and S3. Also the stability of operative temperature should be so, that the target value should be kept at the same level during the 95 % of operating time. The target values for air velocities should be less than 0.14 m/s, 0.17 m/s and 0.20 m/s according to S1, S2 and S3 categories in winter time. The carbon dioxide level should be less than 750 ppm, 900 ppm and 1200 ppm according to categories. The target value of carbon dioxide content should be maintained at the same level during 95 % of operating time. According to the guideline the relative air humidity level during the winter should be more than 25 % for S1. For categories S2 and S3 it’s optional. /9, p. 5-14./

In this thesis all requirements from “Classification of indoor environment” are used as a complement for the Finnish regulation for indoor environment – D2. All experimental data which were getting from measurements of indoor climate in sports facilities are compared with D2 requirements and in addition with LVI 05-10440 EN. The requirements for indoor climate of investigated sports facilities from standard “Classification of indoor environment” summarized in the table 3 according to three categories of quality.

TABLE 3. Requirements for indoor climate from "Classification of indoor environment" /9/

Indoor environment categories	Parameters of Indoor Climate				
	Air temp., °C	R. Hum., %	CO_2 level, ppm	Air Velocity, m/s	Pressure Level, kPa
S1	21.5 ± 0.5	≥ 25	≤ 750	≤ 0.14	-
S2	21.5 ± 1.0	optional	≤ 900	≤ 0.17	-
S3	21.0 ± 1.0	optional	≤ 1200	≤ 0.20	-

3.3.2 Russian standard for indoor environment of sports facilities

The main regulation document for construction in Russia is SNIP. It's abbreviation from Russian language which means National Building Regulation. The SNIP contains compulsory requirements and recommendation for different fields of construction. The structure of SNIP looks like set of regulations for design and construction. It also contains separate standard for design of physical training and sports halls. The name of this standard is SNIP 31-112-2004 "Physical Training and Sports Halls". Into this thesis were reviewed the latest version of standard which was published in 2004. The standard consists of two parts. Each part contains guideline for different fields of design or construction of sports facilities. First part of standard include separate chapter for HVAC design. This chapter contains information and different requirement for indoor environment. In fact, Russian regulations and guidelines for indoor climate aren't containing detailed information, requirements or any target values. The condition of indoor climate described for ordinary sport halls and also there are few parameters of indoor air which should be considered. According to the SNIP, the definition of ordinary sport halls means the place where any kind of sport activities occurs. For instance it may be any sports facilities from sport halls in schools or other education establishment to serious and huge sports centres such as covered stadium or other great sports facilities. So, it means that quality of indoor climate for three investigated facilities must comply with common requirements from standard. /11./

According to the Russian standard indoor air temperature for typical sports halls should lay within the range from 17 °C to 19 °C. Permissible deviation for temperature of indoor air is ± 2.0 °C. The relative air humidity should be maintained in the range from 30 % to 45 %. Air velocity in indoor spaces should be less than 0.2 m/s. There is no detailed information and any others target values for limits of carbon dioxide level of indoor air. Also the standard doesn't contain suitable requirements for indoor air pressure. All requirements for indoor environment of sports facilities are summarized in the table 4 below. /11./

TABLE 4. Requirements for indoor climate from Russian standard /11/

Sports Facilities	Parameters of Indoor Climate				
	Air temp., °C	R. Hum., %	CO_2 level, ppm	Air Velocity, m/s	Pressure Level, kPa
	17 – 19	30 – 45	-	≤ 0.2	-

3.3.3 U.S. guidelines for indoor environment

The most significant publisher of any standards for building services engineering field in United States of America is ASHRAE. The abbreviation of this organization means American Society of Heating, Refrigerating and Air Conditioning Engineers. The first standards from ASHRAE were published in 1895, when the predecessor organization which called as American Society of Heating and Ventilation (ASHVE) was just beginning to create the first versions of the standard on ventilation for all classes of buildings. Another predecessor organization which called as the American Society of Refrigerating Engineers (ASRE) has issued a Safety Code for Mechanical Refrigeration in 1932. Since then, the association ASHRAE has released more than a hundred standards and recommendations that have received world-wide recognition and define standards for heating, ventilation and air conditioning, used all over the world. ASHRAE standard is not mandatory document for designing. /12./

The main regulation and guideline for indoor thermal environment which was issued by ASHRAE is standard 55-2004. The topic of this standard is "Thermal Environmental Conditions for Human Occupancy". This standard was published in 2004. The standard includes some requirements for suitable parameters of indoor thermal environmental factors such as temperature, thermal radiation, humidity, air speed. Also it contains the requirements for personal factors of occupants such as clothing and activity level. The main idea of this standard is to show how all of these factors should be applied into indoor spaces and how these factors should be adjusted in combination with each other to achieve optimal thermal environmental conditions for occupants. Some non thermal environmental factors are not considered in this standard because all of them don't relate with concept of thermal comfort. For instance it may be acoustics, illumination, level of some biological or chemical space contaminants and carbon dioxide level, which was considered in this thesis as one of the environmental indoor factor that play role in formation of suitable indoor climate in sports facilities. So, this guideline includes requirements only for those factors which are related with thermal environmental conditions. /13, p. 3-4./

In fact, the standard does not contain exact values for parameters of indoor environment in any sports facilities or other indoor spaces. But, on the other hands, in contrast with many other standards, this standard describes some new important definition and ways of evaluation of indoor climate. According to the guideline, there are six main factors which should be considered. These factors are metabolic rate, clothing insulation, air temperature, radiant temperature, air speed and humidity level /13, p. 4/. All of these factors in combination with each other may have an impact on the total thermal comfort of person. But every single person perceives these parameters differently, even if we consider one certain indoor space with constant conditions of thermal climate. It depends on the individual sensitive of person and also depends on the metabolic rate and clothing insulation level of this person. /13./

The best explanation of individual satisfaction with thermal conditions for each single person is expressed by using such concepts as PMV and PPD indices. Abbreviation PMV means predicted mean vote. This index expresses the mean vote of group of occupants by using the seven-point thermal sensation scale. The scale range lay from -3 points, which relate to cold conditions of thermal climate, to +3 points, which relate with hot conditions of thermal climate. Abbreviation PPD means predicted percentage of dissatisfied. The value of PPD expressed in percentages and shows the percentage of people who are dissatisfied with condition of thermal climate. This index can be obtained from the value of PMV. /13, p. 3./

Also, the idea to express satisfaction of occupants with indoor climate quality by using such concept as PMV and PPD, is described in several standards about indoor climate from European Union. For instance, these standards are CEN report CR 1752 and ISO 7730. The description and analyze of these standards described in the following section of thesis. The relation between PMV and PPD indices presented graphically at the figure 3. As we can see at this graph, the curve not drops lower than 5 percent of dissatisfied persons. It means that every single person perceived quality and condition of thermal climate in their own way and there are also exceptions in 5 percent of cases. /13, p. 5./

The standard also includes the example of typical description of situation with indoor climate in some ordinary office spaces. This example shows the interrelation between 6 key factors of indoor environment and acceptable comfort zones for occupants according to values of PMV and PPD indices. The example presented graphically at the figure 4.

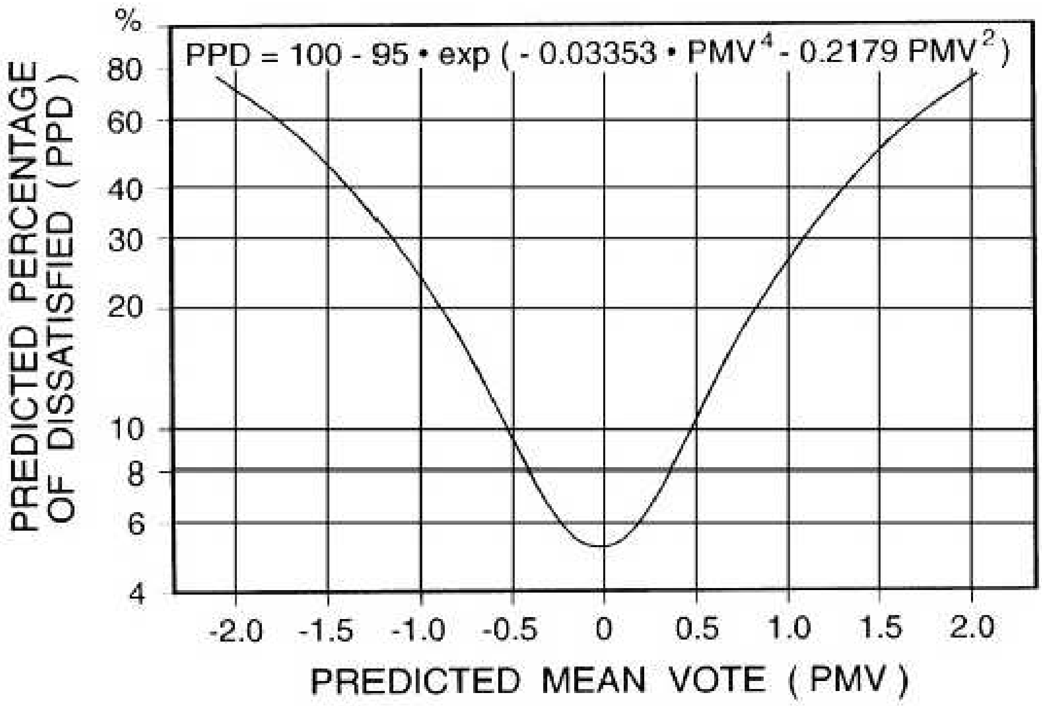

FIGURE 3. Relation between PPD and PMV indices /13, p. 5/

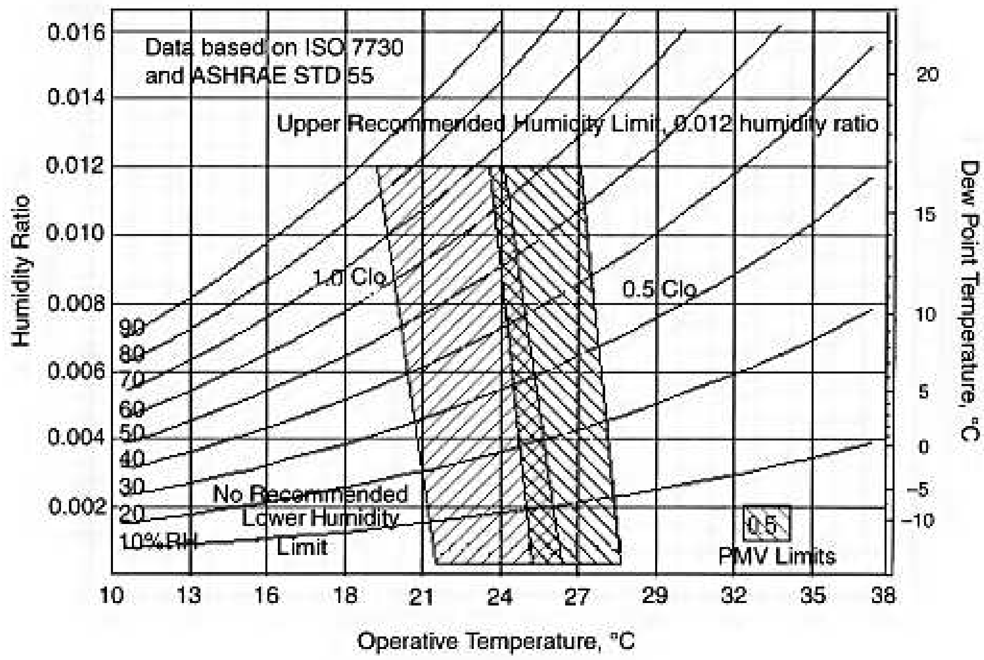

FIGURE 4. Interrelation between 6 key factors of indoor environment and acceptable comfort zones for occupants /13, p. 5/

As we can see, the figure 4 shows two comfort zones for occupants with two different values of clothing insulation. These comfort zones have been determined according to higher and lower recommended limit of humidity and also according to the acceptable temperature range. These zones are really suitable for persons whose range of activity level from 1.0 met to 1.3 met. Also these areas of comfort conditions of indoor climate determined in such way, that the PMV value is 0.5. It means that, according to the graph at figure 3, the amount of dissatisfied persons will be lower than 10 percent from overall quantity. /13, p. 5./

The standard also include appendix with explanation of calculation PMV and PPD values for different conditions of indoor climate. The calculation of PMV and PPD indices can be done by using special computer program which was written on programming language BASIC. For calculation we need to know some input value such as clothing, metabolic rate, external work, temperature of air and mean radiant temperature, relative air velocity, and relative humidity or water vapour pressure. /13, p. 21-22./ European standard ISO 7730 also contains information about calculation of PMV and PPD indices. It should be noted that the similar program for generation graphs which based on PMV and PPD values were developed by company LumaSense Technologies in Microsoft Excel. All examples of calculation PMV and PPD indices for indoor climate of investigated sports facilities and generation of graphs were presented into following chapters of thesis like one of the results of this exploration.

Always may be some percent of dissatisfied persons with quality of indoor environment. There are many reasons for that, but one of the most common is local thermal discomfort which happens due to radiant temperature asymmetry, drafts, vertical difference of air temperature and unsuitable floor temperature. All of these factors and some others may affect at the value of amount persons who are dissatisfied with thermal climate conditions. /13, p. 6-8./

The standard doesn’t include any exact values or even a regulation for indoor environment for sports facilities. The standard contains detailed description of concept of thermal climate. Because of it, it will be impossible to utilize any design criteria for indoor climate into final table with comparison of all standards. On the other side, this regulation document includes very useful information about ways of estimation quality of indoor environment. Also there are descriptions and explanations of key factor which influence on total condition of indoor climate and thermal climate in particular. So, all of these things are very important to provide an accurate investigation of indoor climate.

3.3.4 European Union standards

All countries that are part of the European Union share common European standards - EN. There are three European Standardization Organizations which are involved in the approval of any standards, regulations or guidelines. One of these organizations is CEN. The abbreviation CEN means The European Committee for Standardization. This organization includes 31 members and was established in 1972. All EN standards become national standards in all countries participants of European Union. It means that standards which were considered in this chapter also belong to the national standards of Finland. Also there is one type of international standards commonly known as ISO. This type of standards was published by such organization as International Organization for Standardization which includes 159 members and was established in

1946. Almost all international standards can be included in list of EN and vice-versa. In that case the name of the standard will have a prefix EN ISO. In this chapter the next European standards were considered: EN ISO 7730, EN 15251 and CR 1752. All of these regulations adopted like a Finnish National standards by Finnish Standards Association which have abbreviation SFS. /14./

All investigated standards have some amount of shared information about indoor climate. All of them were published like a separate guideline for various specific purposes but many of them borrow some information from each other. For instance, EN ISO 7730 is quite similar with ASHRAE 55-2004 and with CR 1752. That's why all listed European regulations will consider briefly in the continuation of this chapter. But in any case, some standards complemented others standards and all together these guidelines form the one group of standards for indoor climate which should be taken into account.

One of the International standards for indoor climate which was approved by European committee for standardization (CEN) and was applied as status of National standard in Finland by SFS is EN ISO 7730. The name of this regulation is "Ergonomics of the thermal environment - Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria". The standard has been prepared by technical committee of international organization of standards and approved by CEN in 2005. This standard based on the old version and supersedes it. The old version was published in 1995. /15, p. 1-4./

The standard EN ISO 7730:2005 is quite similar with American standard which named as ASHRAE 55-2004. It's so, because both of these standards were developed in parallel. As well as the American standard 55-2004, ISO 7730 also includes requirements for thermal comfort, quality of indoor environment and it described the ways of evaluation of thermal comfort for occupants. On the other hand, the standard doesn't contain some information or any values for parameters of quality of indoor environment for sports facilities. The principal content of standard has a generalized character and describes the general concepts related to indoor climate and thermal environment. It includes some description of calculations of PMV and PPD indices which was given in previous chapters of thesis. Also this standard includes information about concept of local thermal discomfort and such definitions as metabolic rates and clothing insulation which were mentioned in chapter about ASHRAE standard 55-2004. The most interesting information for investigation work of this thesis placed into quite big part of the standards which include eight appendices.

The most important thing into this standard that should be mentioned is developed classification system for evaluation of thermal environment according to PMV and PPD indices with criteria of local thermal discomfort which is utilized for determination category of indoor environment quality. It should be useful for evaluation of thermal climate quality of investigated sports facilities. The classification of thermal environment provides opportunity to estimate quality of thermal climate according to three categories: A, B and C. Few factors influence on determination of category and they should be measured. First of all, the PPD and PMV should be calculated according to performed measurements. All other factors are part of the group which related to factors of local thermal discomfort. These are draught rate and the percent of dissatisfied caused by such factors as vertical air temperature difference, warm or cool floor and radiant asymmetry. All of listed factors play role in the formation of thermal climate and all of these should be evaluated and measured. The categories of thermal environment and factors which involved into creation of thermal climate are present in the table 5. /15, p. 13./

TABLE 5. Classification of thermal climate /15, p. 13/

Category	Thermal state of the body as a whole		Local discomfort			
	PPD %	PMV	DR %	PD % caused by		
				vertical air temperature difference	warm or cool floor	radiant asymmetry
A	< 6	− 0,2 < PMV < + 0,2	< 10	< 3	< 10	< 5
B	< 10	− 0,5 < PMV < + 0,5	< 20	< 5	< 10	< 5
C	< 15	− 0,7 < PMV < + 0,7	< 30	< 10	< 15	< 10

As we can see from the table above, condition of thermal environment meet certain values of several parameters that should be measured. Almost all values in the table were given in percents, but in fact some of them related with more specific units. For instance, local thermal discomfort caused by vertical air temperature difference meet the values < 2°, < 3°, < 4° according to categories A, B and C. In the same order the values for local thermal discomfort caused by warm or cool floor are the next: 19 to 29 °C, 19 to 29 °C again and from 17 to 31 °C. So, the classification of thermal climate from the standard ISO 7730 is quite useful and it should be considered if the investigation of indoor climate occurs. /15, p. 16./

The standard includes one quite useful table with some design criteria for different kind of indoor spaces. The main criterion for classification of design values for environmental parameters is activity level which measured according to the type of physical activity. All design criteria are summarized in table 6 below. Unfortunately the table doesn't contain design data for sports facilities, but as an example it should be quite closer if design criteria for department store will be taking from the table for investigated indoor climate of sports facilities. The level of physical activity is quite similar for both types of buildings.

TABLE 6. Design criteria for indoor environment /15, p. 17/

Type of building/space	Activity W/m^2	Category	Operative temperature °C		Maximum mean air velocity m/s	
			Summer (cooling season)	Winter (heating season)	Summer (cooling season)	Winter (heating season)
Single office Landscape office Conference room Auditorium Cafeteria/restaurant Classroom	70	A	24,5 ± 1,0	22,0 ± 1,0	0,12	0,10
		B	24,5 ± 1,5	22,0 ± 2,0	0,19	0,16
		C	24,5 ± 2,5	22,0 ± 3,0	0,24	0,21
Kindergarten	81	A	23,5 ± 1,0	20,0 ± 1,0	0,11	0,10
		B	23,5 ± 2,0	22,0 ± 2,5	0,18	0,15
		C	23,5 ± 2,5	22,0 ± 3,5	0,23	0,19
Department store	93	A	23,0 ± 1,0	19,0 ± 1,5	0,16	0,13
		B	23,0 ± 2,0	19,0 ± 3,0	0,20	0,15
		C	23,0 ± 3,0	19,0 ± 4,0	0,23	0,18

The standards contains interesting tables and information for determination of metabolic rates and physical activity level, for estimation of thermal insulation or clothing for various types of wear, and a quite big table for determination of PMV according to the next initial data: activity level, clothing, operative temperature and relative air velocity. Summing up, the standard contains huge amount of useful information about indoor thermal environment, description of ways for designing of suitable values or parameters of thermal climate.

The next regulation document is European standard EN 15251. The topic of this standard is: “Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics”. The considered version was published in 2007. EN 15251 adopted as National Finnish standard by organization SFS. So, it means that all requirements and guidelines in this standard could be applied to target sports facilities which located in Finland. /16, p. 1-4./

The standard includes requirements and designing criteria for indoor climate and thermal environment in particular, and for all factors which related with energy demand. The content of this document in some parts is quite similar with main ideas and concepts from others standards such as ISO 7730 and ASHRAE 55-2004. Especially it concerns of the thermal environment. That’s why the description of the standard was given briefly and the main stress focuses on the description of the special details of the document.

In this regulation document the new classification system for design criteria were applied. For instance, four categories I, II, III and IV for indoor environment were utilized. This system is quite similar with those classifications which were used in other standards. Category I applied for a very sensitive persons who are sick, or for young children, or for elderly persons. Category II meets the modern and normal requirements for indoor environment in new buildings. Category III used for estimation of quite satisfaction quality of indoor climate in existing building. Category IV describes situation when all design criteria for the first three categories are failed. /16, p. 13./

The document includes annexes with requirements and design criteria for suitable level of PPD and PMV indices, for indoor temperature and for condition of thermal environment in general, for indoor air quality and ventilation rate, for lightning, for noise level and so on. The information about indoor air quality describes the requirements for carbon dioxide level also. All data for estimation of carbon dioxide concentration according to four categories were collected in the table 7 below. It should be noted that suitable limits of carbon dioxide level in the table expressed in values which are above the outdoor concentration of carbon dioxide.

TABLE 7. Recommended carbon dioxide concentration /16, p. 36/

Category	Corresponding CO_2 above outdoors in PPM for energy calculations
I	350
II	500
III	800
IV	< 800

Unfortunately, the standards doesn’t contain exact design criteria for indoor environment in sports facilities like many other standards, but in any case, this regulation document is useful for designing of indoor climate.

The last guideline which was considered in the thesis is CR 1752. The abbreviation means “CEN Report” where CEN means European Committee for Standardization from French language. The topic of CEN report 1752 is: “Ventilation for buildings. Design criteria for the indoor environment”. The considered version of document was published by Technical Committee of CEN in 1998. This regulation document also approved as National Finnish standard by organization SFS. /17, p. 1-5./

The standard described requirements for quality of indoor environment in ventilated buildings. Design criteria for indoor climate of different types of building are quite similar with those which were presented in the table 6 of this thesis. The classification for quality of indoor climate according to three categories like in standard ISO 7730 was utilized. Thus the indoor environment can be estimated in accordance with categories A, B or C. The concept of thermal environment in the standard is the same which was described in previous European regulatory documents. So, idea of PMV and PPD indices, the definitions of local thermal discomfort were utilized in this standard in describing of suitable level of thermal climate. It should be noted that more than half content of this document is a part with different appendices which include descriptions of requirements for indoor environment and tables with design criteria for indoor climate.

The most interesting difference of this document compared to the previous one is the presence of ways of evaluation level of carbon dioxide according to the three categories of quality. The evaluation of carbon dioxide is performed in relation with value of perceived air quality which expressed in percents of dissatisfied persons. The main emitter of carbon dioxide is humans. The level of production of carbon dioxide depends on the metabolic rate of humans. Relation between percent of dissatisfied persons and concentration of carbon dioxide according to the categories of estimation presented at the figure 5 below. /17, p. 23-24./

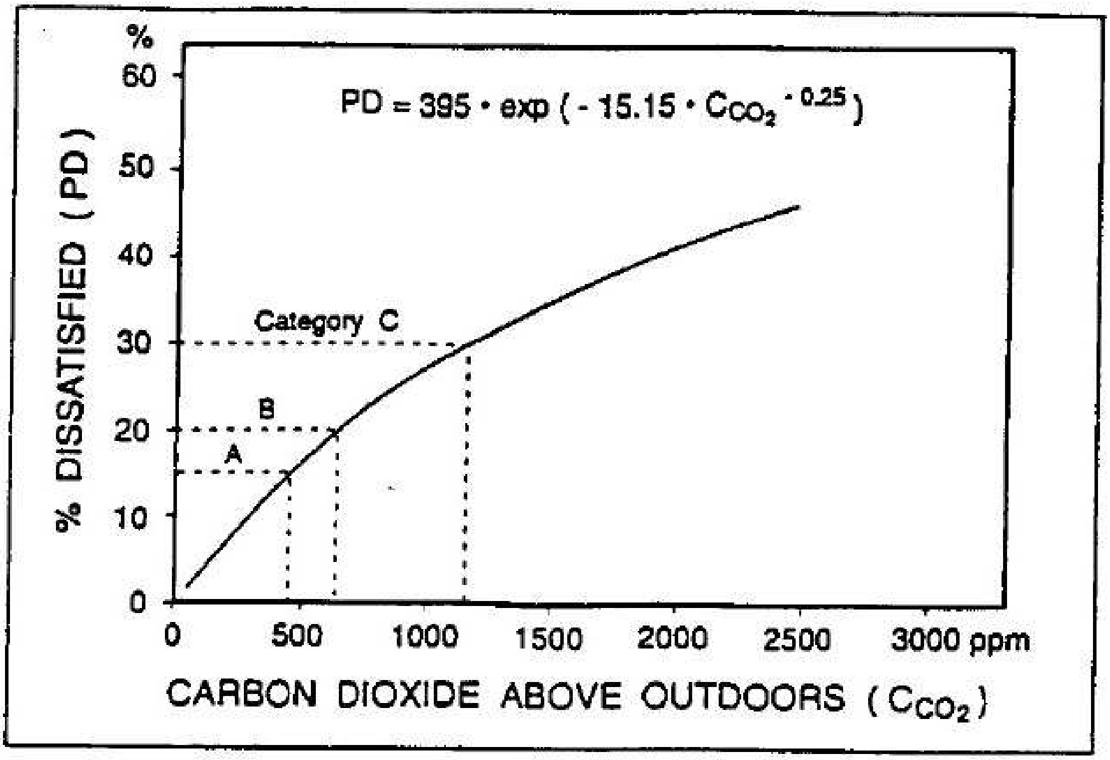

FIGURE 5. Relation between percent of dissatisfied PD and concentration of carbon dioxide /17, p. 24/

The curve at the figure 5 shows the concentration of carbon dioxide on the x axis above outdoors concentration which usually is about 350 ppm. From the figure we can see the exact values of concentration of carbon dioxide and percent of dissatisfied persons according to the three estimation categories. So, the category A corresponds to concentration 450 ppm and about 15 percent of dissatisfied (PD). Category B matches the next criteria: 650 ppm and 20 PD. Category C means that the carbon dioxide level is above than 1150 ppm and this value matches to 30 percent of dissatisfied. This information about suitable level of carbon dioxide is very useful and should be utilized for estimation of indoor air quality in sports facilities. /17, p. 24./

The regulation document includes appendix with description of different pollution sources and the ways of their estimation, appendix with explanation of requirements for acoustic environment, appendix with interesting description the step-by-step method of determination suitable design criteria for indoor climate with practical cases et al. /17, p. 30-40./

The standard contains information about metabolic rates for different cases, description of thermal insulation parameters for some combination of garments. Also it borrows some information from another regulation source which name is “Air quality guideline for Europe”. This guideline was published under authority of World Health Organization (WHO). Thus the standard CR 1752 contains a lot of design criteria for air quality and information about air pollutants and other useful information for designing of indoor environment with high quality. /17, p. 51-58./

All of three considered European regulatory documents were adopted as Finnish standards by SFS. It means that they could be applied while designing of any buildings in Finland. But it should be taken into account that the SFS standards aren’t obligatory in Finland.

3.4 Comparison of standards

The main purpose of standards research is to compare all regulations and guidelines which could be utilized for designing of indoor environment for sports facilities in Finland and to define the best and suitable combination of different requirements for certain parameters of indoor climate into studied sports facilities. The parameters of indoor environment which were considered in this thesis are temperature of indoor air, the air velocity, pressure level, the content of carbon dioxide and humidity level of indoor air. All of these parameters have quite important influence on the total condition of indoor climate. Few documents which have the status of National Finnish standards were investigated in details and all design criteria and requirements for indoor environment are very important and should be considered and compared. For that purpose, it will be useful to create a summary table where all important values for key parameters of indoor environment are summarized and analyzed.

Unfortunately, not all standards contain detailed information about indoor climate in sports facilities in particular. As we can note from the research of standards in this chapter, some regulations include design criteria and requirements which only indirectly affected on state of indoor climate in sports facilities. Other standards contain only general information which describes the way of designing suitable criteria for indoor environment with high quality. For instance, the American standard ASHRAE 55-2004 doesn't include detailed design values for indoor climate which should be compared in the final tables. Instead of it the standard described the ways of evaluation of thermal environment. For that purpose, the main parameters of evaluation of thermal climate are PPD and PMV indices, which also were given in the table with comparison as additional design criteria. It can be useful further in the analysing process of measured data. In any case, for reaching the goal all data and requirements which were given in the considered regulatory documents should be analyzed and compared.

In other words, the goal of this chapter is to develop the system of evaluation the quality of indoor environment in studied sports facilities according to the standards. The system of evaluation should be based on some certain perfect model of indoor climate which was developed according general table with comparison of all collected design criteria. The table with comparison of requirements and design criteria for indoor climate from all studied standards with quite detailed descriptions is given below at the next page (see the table 8).

As we can see, the table 8 contains the cells which are marked by sky blue colour. These areas show design criteria from Finnish standards. In fact, all measured data should be compared with these values in sky blue cells because all three sports facilities located in Mikkeli. The compulsory and strict design criteria for indoor climate in Finland were presented in D2. More detailed estimation of quality of indoor environment can be performed by using the categories from Finnish classification system. If all performed measurements meet design criteria in sky blue cells of table 8, it means that the quality of indoor climate is suitable and corresponds to the requirements from regulatory documents. The values of air temperature from European standards ISO 7730 and EN 15251 were taken as the average between values for summer and winter seasons. Also the data in these standards correspond to design criteria for department store because the high activity level there is quite similar with activity level into sports facilities and because these standards don’t contain design criteria for indoor environment in sports facilities in particular.

TABLE 8. Comparison of design criteria for indoor climate from standards and other documents /6, 7, 13, 15, 16, 17/

Standards		Catego-ries	Design criteria for indoor environment					Additional design values	
			Air temp., °C	R. Hum., %	CO_2, ppm	Air vel., m/s	Pressure, kPa	PPD, %	PMV, units
Finnish	D2	unified	18	20 – 45	≤ 1200	≤ 0.3	101.3	-	-
Finnish	Classification of indoor envi-ronment	S1	21.5 ± 0.5	≥ 25	≤ 750	≤ 0.14	-	-	-
Finnish	Classification of indoor envi-ronment	S2	21.5 ± 1.0	optional	≤ 900	≤ 0.17	-	-	-
Finnish	Classification of indoor envi-ronment	S3	21.0 ± 1.0	optional	≤ 1200	≤ 0.20	-	-	-
Russian	SNIP 31-112-2004	cat. 4 for sport obj.	17.0 – 19.0	30 – 45	-	≤ 0.2	-	-	-
U.S.	ASHRAE 55-2004	-	-	-	-	-	-	< 10	-0.5 < PMV < +0.5
European	EN ISO 7730	A	21.0 ± 1.0	-	-	≤ 0.14	-	< 6	-0.2 < PMV < +0.2
European	EN ISO 7730	B	21.0 ± 2.5	-	-	≤ 0.17	-	< 10	-0.5 < PMV < +0.5
European	EN ISO 7730	C	21.0 ± 3.5	-	-	≤ 0.20	-	< 15	-0.7 < PMV < +0.7
European	EN 15251	I	21.0 ± 1.5	30	≤ 350	-	-	< 6	-0.2 < PMV < +0.2
European	EN 15251	II	20.5 ± 2.5	25	≤ 500	-	-	< 10	-0.5 < PMV < +0.5
European	EN 15251	III	20.5 ± 3.5	20	≤ 800	-	-	< 15	-0.7 < PMV < +0.7
European	EN 15251	IV	-	< 20	> 800	-	-	> 15	PMV> +0.7;< -0.7
European	CR 1752	A	21.0 ± 1.0		≤ 450	≤ 0.14	-	< 6	-0.2 < PMV < +0.2
European	CR 1752	B	21.0 ± 2.5		≤ 650	≤ 0.17	-	< 10	-0.5 < PMV < +0.5
European	CR 1752	C	21.0 ± 3.5		≤ 1150	≤ 0.20	-	< 15	-0.7 < PMV < +0.7

It should be noted, that the data from three European standards are quite similar. Another interesting detail is that only one single standard contains design value for pressure level. It's D2. The average magnitude of air temperature from EN is lower for about 0.5 °C than from Finnish regulatory documents. Also the Russian SNIP requires quite low air temperature for sports facilities in comparison with all others standards. The range of relative humidity for all considered standards is from 20 % to 45 % in average. Requirements for carbon dioxide level from EN is much stringent than in Finnish standards. Interesting thing is that the design values of air velocities from all considered standards are almost identical. The highest limit of air velocities is 0.3 m/s. The PMV and PPD indices were present as additional design criteria for more detailed estimation of indoor climate quality and thermal environment in particular. It's useful to know these indices for research sports facilities and they will be determined further into next chapters for each single case.

After analyzing the table 8, we can determine the best, strictest and most appropriate design criteria for indoor environment as result of comparison of all regulatory documents and standards which were given in the table. For that purpose, we should take lower compulsory limits for each of researched parameters or just take an average magnitude in some cases. Thus we can get a new set of parameters for indoor environment by which the total condition of indoor climate will be improved and became a most suitable for performing different kind of sports events. The result of analyzing data is presented into table 9 below.

TABLE 9. The strictest set of parameters for condition of indoor climate

Parameters of Indoor Climate						
Air temp., °C	R. Hum., %	CO_2, ppm	Air vel., m/s	Press., kPa	PPD, %	PMV, units
18 ± 0.5	32.0 ± 5.0	≤ 350	≤ 0.14	101.3	< 6	-0.2<PMV< +0.2

The table 9 was created and analyzed according to all regulatory documents which were researched in this thesis. The magnitudes of indoor air temperature as well as relative humidity are average for all values which are presented in standards. Requirements for pressure level have been described only in one single standard – Finnish D2. The rest values of carbon dioxide level, air velocity, PPD and PMV indices were given as the most lowest from all researched regulatory documents. As a result we got the table which contains best design criteria for comfortable and suitable condition of all parameters which related with concept of indoor environment in sports facilities.

To summarize this chapter we can note that the research of different regulatory documents and their sequential analysis and comparison allow getting quite clear and effective way for evaluation of quality of indoor environment in sports facilities. It will be very useful further when the all measured parameters of indoor climate condition will have to be evaluated and compared with requirements of Finnish standards and other researched standards. In such a way we can get an answer on questions: “Is the quality of indoor environment in sports facilities meets the compulsory requirements from regulatory documents? Is it possible to perform the sports events of high and international level there or not? ”. Thus the main goal of this chapter which describes researching of few regulatory documents has been achieved. All measured experimental data can be objectively evaluated and analyzed.

4 MATERIALS AND METHODS

4.1 General overview

This chapter presents the objects of the research and methods which were used during performing of this investigation. The three objects of investigation are air-supported structure, sport hall and gym. Also the one general target for research is indoor climate in each sports facility. This part of research work is main part because there are presented description off all processes of measurement – it's an experimental part of work. All results of this thesis are based on the data from measurements in all investigated sports facilities.

4.2 Description of the buildings

Detailed description each of three sports facilities and their features are presented. Also there is some theoretical information about general characteristics of sports facilities, some typical features and properties. Each sports facility was discussed in details and also all relevant materials such as photos and schemes are attached.

4.2.1 Air-supported structure

Nowadays, air-supported structures are often used for indoor sports. One advantage of air dome is that there can be large sports facilities such as soccer fields, volleyball and basketball courts, tennis courts, artificial ice rinks, etc. Also it requires a quite small investment for the construction in comparison with other types of indoor sports facilities. Another advantage of air-supported structure is the possibility of repeated assembly and disassembly facility at almost any type of soil, and the ability to cover large areas (500-5000 sq. m.) without building the supports of elements in buildings.

There are two mounting system of inflatable structures to the ground: anchoring and fastening system on the prepared concrete foundation. The air-supported structure should be attached to the ground quite strongly. It's so, because the whole foundation system should provide good resistance against the lifting force which is cause by overpressure level inside the dome. Also foundation system should provide good resistance against the wind's forces. The best solution in that case is to utilize system of ballast anchorage. /18./

The shape of such type of construction is usually oval, domes or hemispheres. The scheme of typical air-supported structure is presented at the figure 6 below. /18./

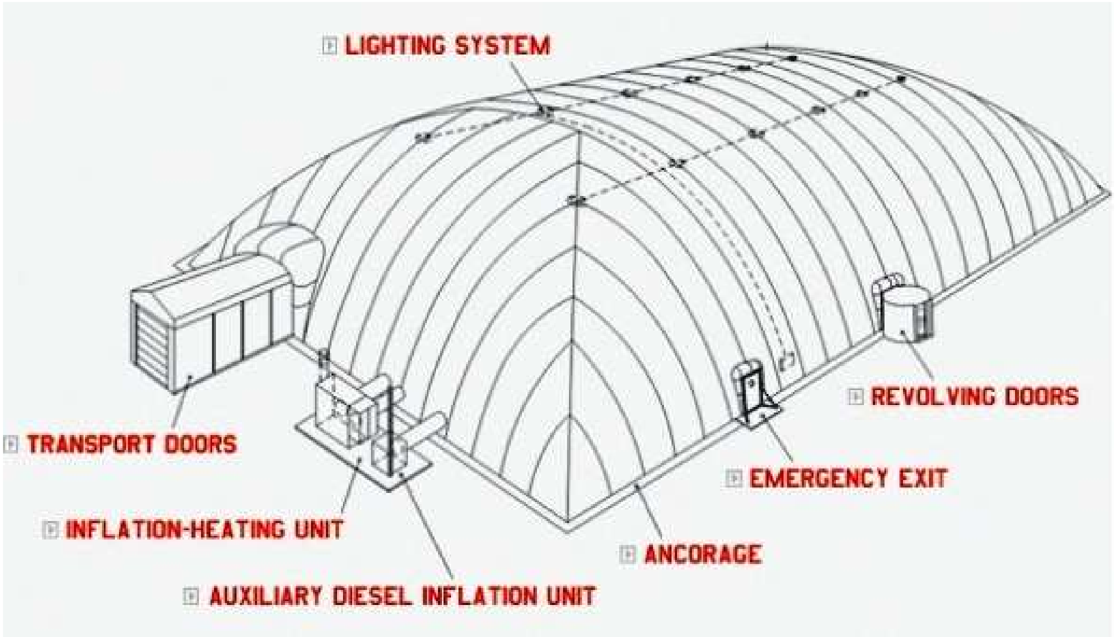

FIGURE 6. The typical air-supported structure /19/

As you can see, at the figure 6 are presented different typical features of air-supported structure. Usually, each air dome has three types of entrance or exit. One is the main door which should insulate indoor air into dome from outdoor environment. For that purpose usually revolving doors or another type of airlocks should be installed. The second type is emergency exit. It’s always necessary according to the fire safety guidelines. Third type of entrance is mounted for transport purpose. Transport doors are needed for possibility to install appropriate oversized sports or engineering equipments inside the air dome.

The air-supported structure is equipped by lighting system. It’s shown at the figure 6. In fact the sunlight can pass into the dome through envelope, but usually in countries with northern climate the duration of day is not too long so the lighting system is necessary part inside the air dome. Also all air-supported structures should be equipped with special engineering devices for maintaining air inside the dome which keep it at the constant level. At the figure 6, it's inflation-heating unit – part of whole ventilation system of air dome. Otherwise, if the pressure level inside the dome is not high enough, structure begins falling down and stop to function until air supply system starts to resume maintaining the air. The special emergency supply devices should be utilized to prevent such undesirable case. At the figure 6, it's auxiliary diesel inflation unit. It works independently from electricity and should resume maintaining of air into the dome in different emergency cases. /19./

The Air dome is a structure which is made from solid multilayer membrane. For instance, it maybe: fibreglass, polyester, teflon or PVC. This membrane is an envelope of whole structure. Membrane protects the interior space from the weather conditions and also allows sunlight pass through the envelope of air dome by 75%. To seal envelope of structure are utilized special airlocks as doors or also possible to install the revolving doors which are very convenient for visitors during the operation. /18./

The principle of operation of the design is based on maintaining a slight overpressure inside the air-supported structures by injecting fresh air ventilation unit. The average pressure level inside the dome is about 150-750 Pa. The pressure and temperature in the air dome are controlled by automatic system, which indicates the temperature, wind speed and humidity of the outdoor environment. In the case of snow, temperature under the envelope of structure is automatically increased to allow the snow to melt. /18./

Air dome is equipped by an emergency autonomous system, which begins to maintain the pressure level in the event of damage electricity. Air supported structures are adapted to the northern climate with its unpredictable changes in temperature. It can work even if the velocity of wind is about 150 km/h. They are equipped with heating and ventilation systems and can withstand temperature variations from -50 to +70 C. Also, the system is complemented by the heating coil with variety sources (electric or water), heat pumps, humidifiers or dehumidifiers. /18./

The studied air dome is located in the city of Mikkeli. The kind of ground under the basement of sports facility is a rather dense soil. But anyway, the total weight of air-supported structure with its basement is not too high. Therefore the construction doesn't need any special requirements for condition of soil. The air dome is attached to the ground by system of ballast anchorage. External appearance of investigated air-supported structure is presented at the figure 7.

FIGURE 7. Air-supported structure in Mikkeli, Finland

This air dome is used for training and sport competitions such as football, athletics and rugby. Due to the air dome include few football gates which are different in their sizes. The overall capacity of the structure is 200 persons. It’s a typical air dome which has a hemispheric shape, envelope material is multilayer membrane. Material of membrane is polyvinyl chloride which is also named as PVC. The air dome is equipped with ventilation system and a system for maintaining the pressure – to pump air from environment inside to the dome. The lighting inside the dome consist of system a spotlights which illuminate a surface of the field on a suitable level. Also there are two dressing rooms inside the structure and three toilets. In the air dome installed the special football floor covering which an artificial herbaceous cover is made of synthetic fibres. The internal appearance of air-supported structure is presented at the figure 8 below.

FIGURE 8. Internal appearance of air dome

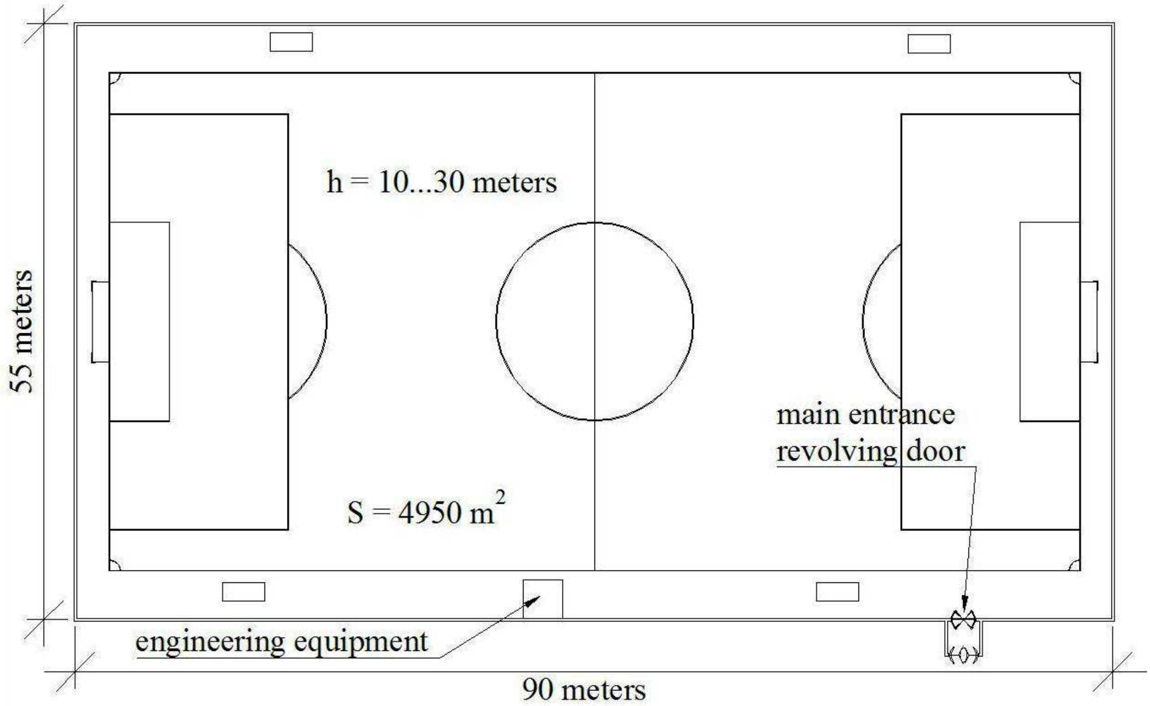

FIGURE 9. Scheme of air dome. Top view (plan)

The length of the football field inside the dome is about 90 meters and the width is about 55 meters. Total area of football field in air dome is a little bit less than 5000 square meters. The entrance has revolving doors which insulate the indoor climate of air-supported structure from outdoor environment and helps to keep certain pressure level inside the dome. Dimensions of the dome, location of engineering equipment, the disposition of furnishings and sports equipments and central entrance are shown at the figure 9.

According to the aims of this bachelor thesis all relevant measurement of indoor climate parameters were done in investigated air dome. The scheme of measurements and description of measuring method which was applied during the research work are given in the following chapters.

4.2.2 Sport hall

Usually, the sport hall is a special space where different sport equipment or exercise machines are installed. It’s designed for sports games, sports or physical education. There are many types of sport halls. Some of them are designed specifically for certain kind of sports and some of them have multipurpose functions. Typical sports halls are held in almost all secondary and higher education institutions around the world. Often it includes both fixed and demountable sports equipment that allows you to transform them into volleyball, basketball, badminton or into another sport court. The floor covering in such ordinary sport halls is usually sports linoleum which is made from PVC or sports wooden parquet. According to new standards all sport halls should be equipped by air ventilation and conditioning system for create suitable conditions of indoor climate but quite often it’s not so, because many of sport hall were built when the standards weren’t exist yet. /20./

The sport hall which was investigated in this thesis is located in city of Finland – Mikkeli. It’s a part of the campus of Mikkeli University of Applied Since. The sports hall is located into D-building which is also a part of MUAS campus. D-building includes many types of premises such as auditorium, classrooms, canteen, several laboratories and sport hall also. General appearance of sport hall is presented at the figure 10 below.

FIGURE 10. General appearance of sport hall in D-building of MUAS

The investigated sport hall is a multipurpose sport facility. It can be used for different kind of sport and physical exercises because the sport hall contain many sport equipments such as basketball rings, nets for volleyball and badminton, gates for mini football and for floorball games, gymnastic balls, mats, sticks, different balls, wall bars for exercises and so on. Also the floor into sport hall was painted by special stripes. It's marking for different kind of sports. So, the sport hall can be used for such kind of sport activity like basketball, volleyball, mini football, floorball and other type of physical exercises and gymnastics.

The envelope of sport hall includes one quite huge window which is installed in such way that it covers the area from floor to ceiling. The width of that window is 3.2 meters. The floor covering of sport hall made of wooden parquet which is protected by a layer of lacquer. Also sport hall is equipped by modern ventilation and air conditioning system. It is possible to control some parameters of indoor climate in sport hall. But it depends on the type of air ventilation machine which handles the intake air. The air ventilation system is presented at the figure 11 below.

FIGURE 11. Ventilation and Air-conditioning system in the sport hall

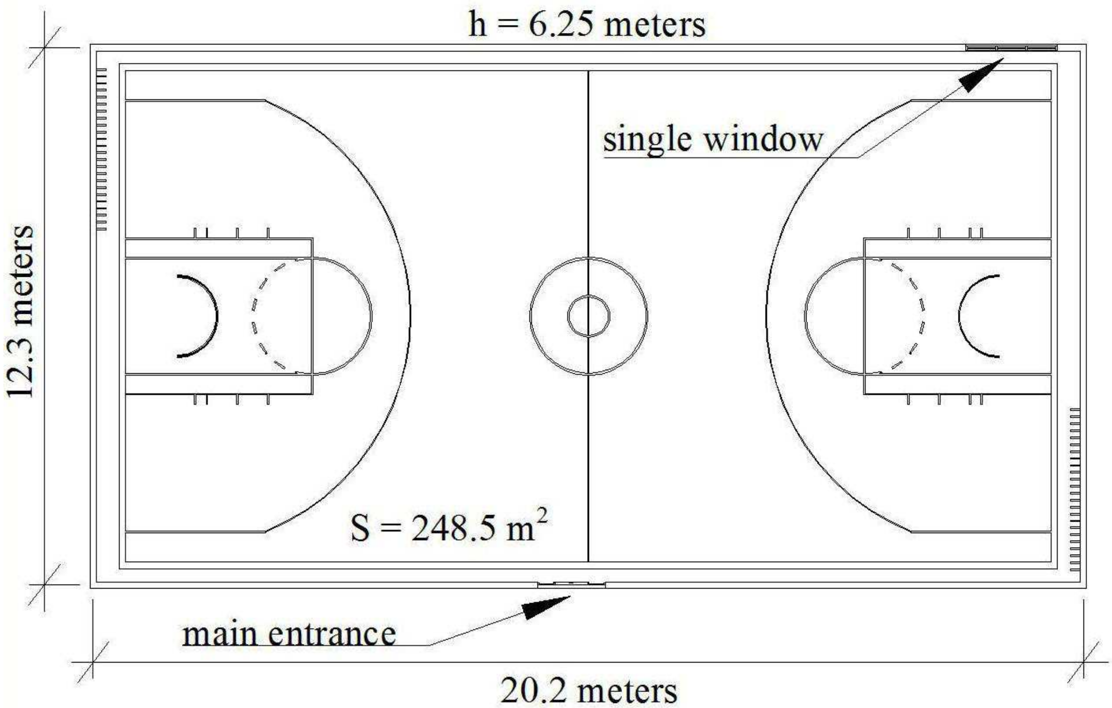

FIGURE 12. Scheme of sports hall into D-building. Top view (plan)

The sport hall which was investigated have only one entrance door. The height of sport hall is about 6.25 meters. Length and width of hall is about 20.2 meters and 12.3 meters respectively. All important dimensions are presented at the figure 12 below. The total area of a sports hall is 248.5 m^2. According to the aims of this bachelor thesis all relevant measurements of indoor climate parameters were done in the investigated object.

4.2.3 Gym

Typical gym is a place for many kind of sports and physical activities. Usually, gym is equipped with special devices which are used by visitors for physical work. Gym should include aerobic exerciser, fitness cycles, sports and gaming complex, stack gyms, physical simulators, steppers and fitness machines which are also contain different racks with barbells, dumbbells and barbells themselves and exercise equipment with built-in scales. All of these things are installed often in the common room which is named like gym. Also the mirrors are installed at the walls of gym room for purpose of monitoring the process of performing different exercises. The requirements for total area of such room for gym aren't too big. In fact, standard area of room with different fitness machines is 200-300 m^2, but it depends on the total amount of visitors and total amount of exercise equipment. /21./

The main difference between sports hall and the gym is that the sports hall can be used for various competitions and gym are using exclusively for individual training. Based on the different purpose of each sport facilities, design of sports hall and gym is significantly different as well, although the requirements for indoor climate are basically the same. The gym should be equipped with modern air conditioning and ventilation system for the purpose of maintaining good indoor air quality. It's very important because the gym is also sports facilities where physical and sports activities are performed.

The gym which was investigated in this research work is located in eastern city of Finland – Mikkeli. The gym consists of different rooms: two dressing rooms which have showers, main corridor and two rooms which is main parts of gym – operating zone for the purpose of physical activities. These all rooms of gym are located in the second storey of the building which named as U-building. The U-building is a part of the campus of Mikkeli University of Applied Sciences. Operating zone of gym include two rooms which were investigated. Design of both rooms is quite similar but the purposes of each room are different. Due to the requirements for indoor climate in each room are also different. Both rooms are connected by one door between. The overall appearance of the room is presented at the figure 13 below.

FIGURE 13. Overall appearance of the gym

The main purpose of the room is different physical exercises such as aerobic, rhythmic aerobic, gymnastics and yoga. The room is used for classes in material arts such as boxing, judo, various types of mat wrestling; the punching bag is mounted to the ceiling at the middle of the room and so on. Thus, the room is equipped by mats, gymnastics balls, devices for step aerobics and etc. The height of the room is about 3.2 meters. Nine identical windows are installed at the external walls. This fact may cause a quite serious load on a heating system of the building. Also this circumstance has effect on a thermal climate. Three external walls separate outdoor environment from the indoor space of the room. This room have a Γ-shape. All design characteristics and some key dimensions of this room are presented at the figure 14 below.

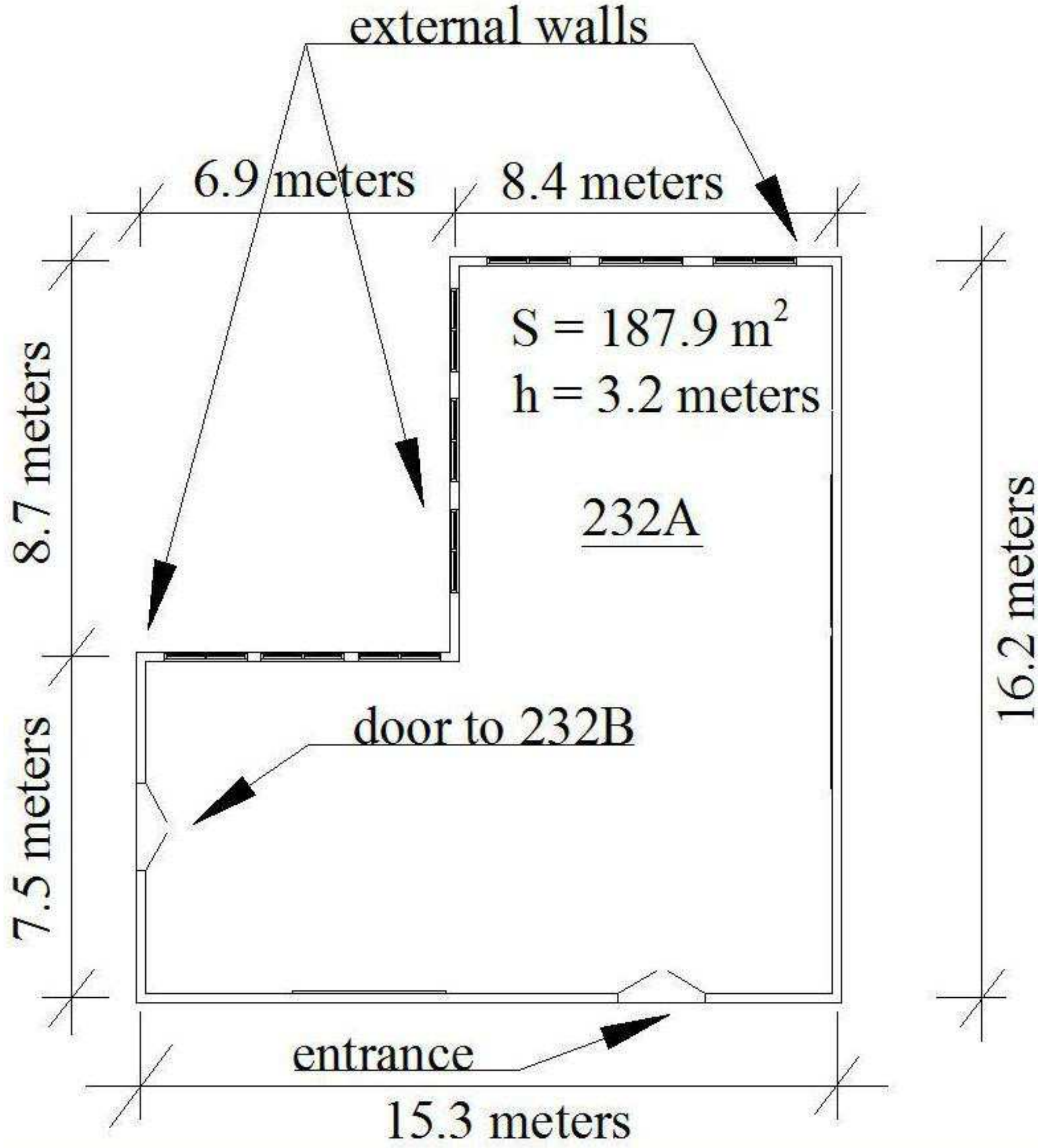

FIGURE 14. Scheme of the room 232A into the gym

The gym has also an other room designed for strength trainings with a variety of exercise machines. In the room are fitness machines, different types of racks with barbells, dumbbells and barbells, exercise equipment with built-in scales, stack simulators, steppers, and three bicycles simulators. Also a few mirrors are installed at the wall of room with purpose to monitoring the quality of performing exercises. The overall appearance of the room is presented at the figure 15 below.

FIGURE 15. Overall appearance of the exercise room in the gym

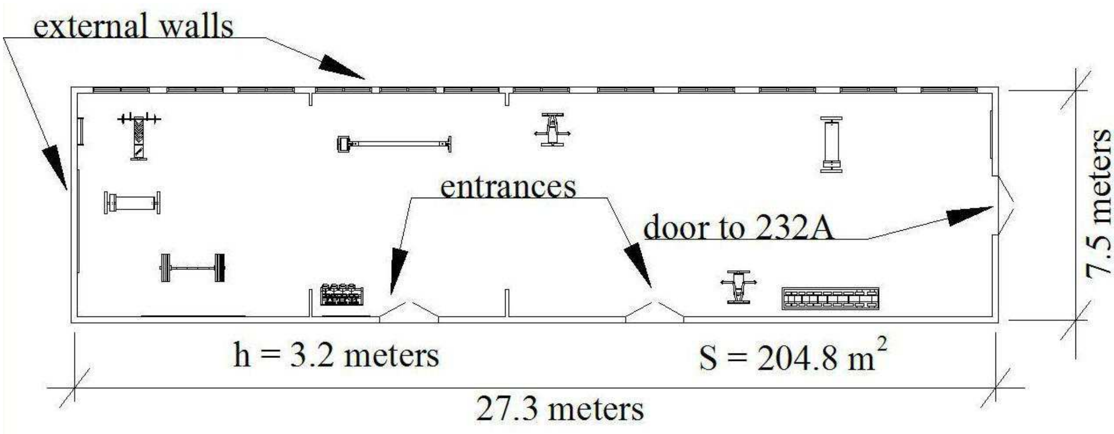

FIGURE 16. Scheme of the exercise room in the gym

The height of room is 3.2 meters. The total numbers of external wall are two. The 12 windows are mounted at the walls. The room have a rectangular shape. All design characteristics and sizes of this room are presented at the figure 16. The detailed description of measuring point's disposition was given in the next chapter.

Both rooms of the gym are equipped with common air conditioning and ventilation system. The system includes supply and exhaust terminal units. This system didn't utilize the separate air handling unit (AHU). Instead of it the outdoor air is handling by local AHU which is installed at the starting duct of ventilation system close to external wall. The AHU heat the air for certain conditions and pump it further through ventilation ducts to the supply terminal units. The outdoor air is intake through outdoor air grill which is located just above the window. So, the air conditioning and ventilation system is quite simple. The system is equipped by two temperature sensors which are show the temperature of intake air and supply air. While the measurements of indoor climate parameters are performed, the temperature of intake air was about 10 °C and the temperature of supply air was about 23 °C. These values are very important and should be taken into account in further calculations.

For this moment, we have a fairly clear picture about objects of research: the dimensions of investigated spaces, the purpose of these premises and activities which should occur in there, such things as furnishings and other important features of these investigated indoor spaces. Thus, we have initial data for planning of each step of measurements. The further descriptions and explanations are given in the following chapter.

4.3 Description of the measurements

This chapter presents description of different measurements, technical devices which were used for getting data for evaluation of indoor air and the ways of investigation of indoor environment. Each measurement is discussed in details and also all relevant materials such as photos, schemes and calculations are attached. Investigation of target sports facilities performed according to existing standards and regulation which describe the process of measurements, the different ways of getting the correct data and further analyzing of them. These standards are SFS 5511, SFS 5512 and EN ISO 7726 which contain detail descriptions and requirements for correct performing of measurements. Also another standard was examined. It's Russian standard GOST 30494-96 which describes the better measuring methods for investigation of indoor environment. These regulations get us the answers on such important questions like: how to make a good measurement planning, how to choose the most suitable measurements locations, which measurements methods exist and should be utilized. The study of indoor climate should be carefully planned and performed in such way, that it gives us the maximum information about the case. Thus all measurements were performed according to recommendations which were described in these regulation documents. As was written above the most important physical parameters which should be measured and which give the full picture of indoor climate situation are air humidity, air temperature, airflow velocity, carbon dioxide level and indoor air pressure. Another thing which should be noted is the measuring devices. The instrumentations should used according to the special instructions and recommendation which contain complete with appliances. Also all calibration procedures must be performed before using of devises. So, further there is an explanation and description of instrumentation and measuring methods based on regulation documents of each physical parameter of indoor climate.

One of the basic physical values which affects the condition of indoor environment is air temperature. This parameter depends also on several factors: humidity of air, air velocity and draught. All of them affect on the general condition of indoor air and each of them takes a role in forming of indoor climate. In its turn, the air temperature consists of the radiant temperature (e.g. the temperature of different surfaces such as windows or radiators), heat losses from human body and from other things (e.g. computers, fridges and other equipments) and so on. The sum of all thermal factors composes the operative temperature. In fact, the temperature of air which is given in most regulation documents and standards is operative temperature. The special device should be utilized for measuring of air temperature during the experiment – data logger. The model of measuring device is Ebro EBI-20TH. The overall view of this device presented at the figure 17. This device has one significant feature: it possible to make a monitoring of air temperature and humidity values during the some certain period of time by using this device. Thus it possible to collect the data and based on it to make a curve which shows the air temperature changes. We can analyze how the temperature changes according to any disturbance which can happen into the target premises (e.g. weather changes or some changes inside the building). We can calculate the average temperature for the whole day by using the data of temperature measurements. According to ISO 7726 the desirable accuracy of measuring is ± 0.2 °C. The data logger meets this requirement. Also, the measurement range for this device is from -30 °C to +60 °C. Some other kind of sampling devices which is also used in research work have function as temperature measuring. But all of them can take only one single sampling during some short period of time as 1 minute. It means that some unexpected factor can effect on result of measurements. In this research only data loggers were used for air temperature measuring.

There are several methods of measuring temperature of indoor air. The description of these methods is presented in corresponding standards. Quite important thing is to choose the right position for measuring points. The basic concept of measuring the temperature of air consists on next several ideas: the samplings should be taken from the occupied zone of indoor spaces; the minimum distance from surfaces which cause radiant temperature such as outer wall, radiators and windows to measuring point should be higher than 0.5 meters – protection distance against radiation; the number of measuring points and total amount of samplings should exclude impermanent changes and other undesirable effects on the final result of experiment. These are the basic ideas and requirements which were taken into account while the air temperature was measured.

FIGURE 17. Ebro EBI-20TH. Monitoring of temperature and humidity of the air

The next physical value which affects on total condition of indoor climate is air humidity. This value was measured with data logger also because this device can make samplings of air temperature and air humidity level in parallel. It should be noted, that there are two main ways to express the value of total level of humidity in the air. The air humidity was expressed as relative and absolute humidity. Both definitions are given in the standard ISO 7730, which gives information about ways of measuring and detecting air humidity level. The main definition or idea about absolute and relative humidity also was given in the standard. The absolute humidity is usually expressed in grams of water vapour contained in 1 kilogram of dry air and marked as [g/kg]. So, the absolute humidity expresses the total amount of water vapour in any amount of air. In contrast with it, the relative humidity expresses only the relation between certain amount of water vapour to maximum possible content of it in the air at the certain air temperature and air pressure. The relative humidity levels are expressed as a percentage. As we can see, the air humidity level is quite closely related with air temperature and air pressure level. All of these three physical quantities depend on each other. The data logger expresses level of air humidity as relative humidity. In fact, all requirements from regulation documents in regard to air humidity were given like relative humidity which expressed in percentages. Thus the data logger is suitable instrument for measuring humidity level. It should be noted that there are two ways of determination of humidity: direct and indirect. The direct way means applying any special instruments such as dew-point or electrolytic. The indirect way means measuring several physical parameters and processing of them. These quantities are temperature and absolute humidity of air and pressure level. All of them should were measured simultaneously. After that we should made a calculation according to the obtained data. In this bachelor work both ways of investigation were utilized. The results of research were presented further. /15, p. 3./

The measurements of air humidity were performed by using the same way as measuring of air temperature. The disposition of measuring points in case of air humidity measuring is absolutely equal to disposition of measuring point while the air temperature was sampled. As was said above, the data logger allows collecting data during the long period of time. So, the final result of air temperature and humidity looks likes monitoring report. As in case with air temperature there are also several rules for principle of air humidity measuring. First of all, all windows into premises must be closed to prevent influence of outside weather. Also it’s better to write down the quantity of humidity level for outside air according to the information from local meteorological station. The number of measuring points should prevent any possible extra influence on the final result. All measurements were performed according to these rules.

The third physical value which is important in forming of thermal climate is air velocity. In fact, the thermal climate was expressed by three main physical characteristics: air temperature, air humidity and air velocity. The relation between these three parameters was shown at the figure 2 into the chapter 3 of this thesis. In its turn, thermal climate with several parameters compose the indoor climate. Actually, the most suitable term for expressing the speed of air isn't the just velocity, but the velocity of air movements or even the draught - the key word in this definition is "air movements". The typical range for velocity of air movements indoors is lay from 0.1 to 0.3 m/s. The term air velocity is appropriate for expressing of air velocity in ventilation ducts. In the duct velocities (air flow, air jet) can reach 5-7 m/s or even higher. So, the most interesting quantity which should be measured is the velocity of air movements. The limit values for that physical parameter were given in most regulation documents and expressed in the unit [m/s].

The air movements can be characterized by using another description. This description is based on the principle that air temperature, humidity level and air movements take role in forming of thermal climate. Thus the second expression of air movements depends on the rest two physical factors: air temperature and air velocity. The draught rate or DR is another quantity for velocity of air movements. The unit's of this value is percentage of draft rate. The Swema air 300 was utilized in the experiment of this research work. This device can measure air temperature, velocity of air movements and draught rate (based on three minute averages). The draft rate calculation is based on three values: air temperature, turbulence intensity and velocity of air movements. In this way we should apply certain equation which was described in the next chapter. The standards CR 1752 and ISO 7730 contain requirements for target values of DR.

Measuring of air movements should be performed according to certain set of rules and requirements which are given in several appropriate standards. The measurement point must locate at the certain distance from any potential source of disturbance of air environment – protection distance. The possible sources of air environment disturbance are terminal units of air ventilation systems, open windows, openings through doors, windows or external walls and so on. Duration of samplings should be at least more than 1 minute. The amount of measuring points and their disposition should prevent any possible interference and disturbance for performing of research experiment. As said above, for measuring of air movements and draught rate the special instrument was utilized – Swema Air 300. All samplings were held by special very sensitive probe. Measuring range of this device is from 0.05 to 3 m/s. The sampling interval 0.1 sec. Accuracy of the device is ± 0.03 m/s. All of these technical parameters meet the requirements from regulation documents totally. The overall appearance of device presents at the figure 18 below.

FIGURE 18. Swema air 300 with probe

Carbon dioxide (CO_2) level of indoor air shows the purities of air. Level of CO_2 involved in forming of quality of indoor air. This physical quantity is quite important especially for indoor environment of sport facilities. It's so because the sportsmen need more oxygen while some physical activities were performed. According to standards which describe the process of measuring there are several rule and requirements for sampling of CO_2 level. The best time for measuring is the end of the day – the worst case. In this case indoor air contain maximum amount of carbon dioxide. If the results of samplings will meet the required limits in such worst case it means that indoor air quality is suitable for sure. The measurements must be performed in such a way that avoids the effect from breath of person who performs the measurements. Also the possible effect on result of measuring from the open windows and other openings must be taken into account by researcher. In fact mainly all measurements should held in a situation when all possible random effects or disturbance are prevented. Disposition of measuring points should be organized in such a way that to get a results which are as closest to real situation as it possible.

Special instrument was utilized for measuring of carbon dioxide level. This is the TSI 460 airflow. There are quite many modifications of this device. The special probe was applied with main device for research of indoor air quality and getting samplings of CO2 level. The TSI can collect the data by defined intervals of time. It’s quite useful for monitoring of situation with CO2 level. Duration of sampling during the research was 1 minute for each of three cases. Possible range of samplings is from 0 to 5000 ppm. Unit ppm was utilized as CO2 level’s units and means amount of particles per million. Accuracy of instrument is ± 3 % or ± 50 ppm and resolution of samplings is 1 ppm. The technical parameters of instrument comply with requirements of standards for performing of measurements totally. The overall appearance of the device presents at the figure 19 below.

FIGURE 19. TSI 460 Airflow with CO2 probe

Finally, the last physical parameter which has influence on the indoor climate quality and were considered and measured in this research work is pressure level of indoor air. In fact, there are several terms of pressure level: overpressure, underpressure and absolute pressure. The overpressure and underpressure is the difference between absolute pressure level of indoors and outdoors. This physical quantity involved in forming indoor environmental conditions and may effect on a health of a sportsmen. So, it’s quite important to know and to control the pressure level. The units of pressure are different. In practice, it's usually Pascals [Pa] which are part of International System of Units - SI. One Pascal is equal to one Newton per square meter [N/m^2]. Also some other units can be applied for describing of pressure level, such as bar, technical atmosphere [am] and standard atmosphere [atm], millimeters of mercury [mmHg] or meters of water column [mW]. Very often bars were utilized in HVAC systems for measuring of different of pressure between any points in some system. Also some measuring instruments such as pressure manometers for example have bar marking scale. Technical atmosphere pressure is quite close to standard pressure of atmosphere and equal to 101.325 kPa. In meteorological practice the millimeters of mercury were utilized. The standard atmospheric pressure is equal to 760 mm of Hg. Next equation shows the relation between all of these units:

$$1 \text{ bar} = 100\,000 \text{ Pa} = 100 \text{ kPa} = 1.02 \text{ at} = 0.987 \text{ atm} = 750 \text{ mmHg} = 10.197 \text{ mW} \quad (1)$$

Into this research work the direct way of measurements of indoor pressure level were applied. For these purpose two instruments were utilized. First device is Alnor AXD 530. It's a micromanometer which can measure differential pressure. Thus this device intended for fixing of underpressure or overpressure levels indoors or outdoors respectively. The scale marked in Pascals. The range of samplings lays from -250 Pa to 2500 Pa. Accuracy of measurements is about ± 1 %. All of these parameters meet the requirements for instruments which are described in regulation documents. The overall appearance of device presents at the figure 20 below. The device equipped by two pipes with open ends. The process of measurement performs indoors. One open-end of first pipe should be located outdoors while the second open-end of pipe – indoors. Thus the display of instrument shows us the differential pressure level between open-ends of pipes. In other words the device fix the difference between outdoor pressure and indoor. The best measuring point is near the window or another opening in outer wall. All factors which can effect on the result of measuring should be taken into account. These factors may be wind outside the building, which can be too strong and have influence on the pressure level near open-end of pipe, rain and so on.

FIGURE 20. Alnor AXD 530. Micromanometer with tubes

Second way of measuring pressure is direct measurements of absolute pressure level indoors. For that purpose the Aneroid barometer were utilized. The construction of device is quite simple in comparison with electric instrument Alnor AXD 530. The aneroid barometer is quite common instruments for measuring absolute pressure level. The first such devices have been used in the 19th century. Nowadays the aneroid barometer apply as measuring instruments almost everywhere in meteorological and private practice, for research of environment and so on. The measurements of indoor pressure level were performed by using barometer which was manufactured in USSR. The scale marked in kilopascals and scale resolution is 100 Pa. Approximate accuracy of measurements is ± 50 Pa. The overview of this instruments presents at the figure 21.

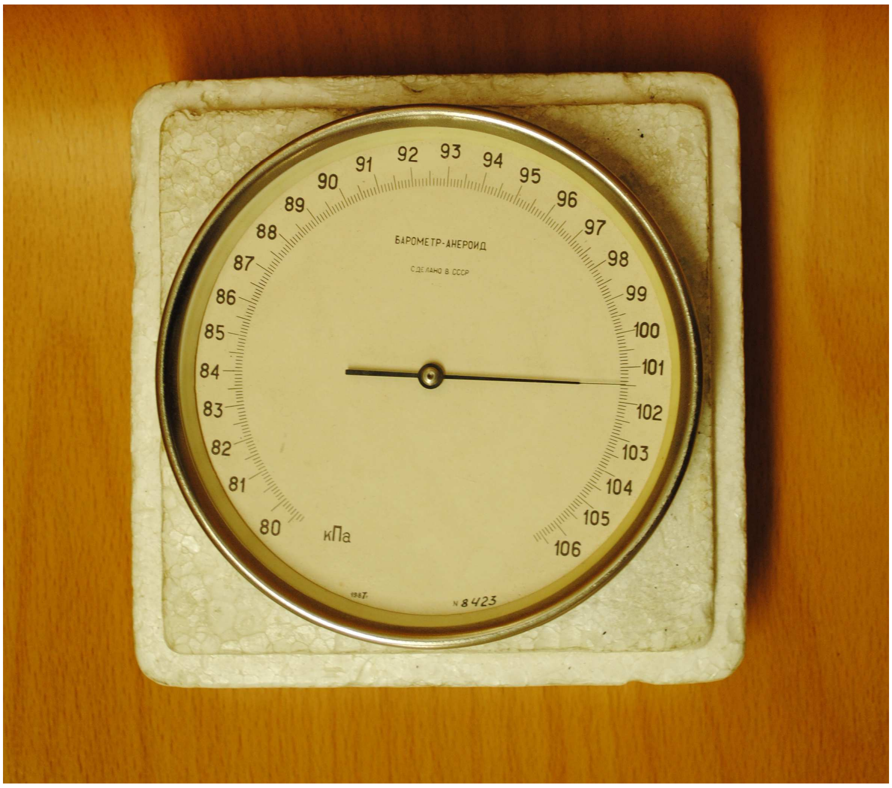

FIGURE 21. Aneroid barometer. Absolute pressure level

The process of measuring is quite common for all three types of buildings. The main principles were described in appropriate regulation documents. The devices must be utilized according to the manuals. Calibration of all instruments performed and presented at appendix 1. Some calibrations performed by special organization which forms a calibration report for device. All such report presents at appendix 1 also. Some others calibrations performed by researcher according to the instructions. The main goal of calibration is to show adequate and corrected results of measuring. While the measuring performed all parameters of outdoor environmental should be fixed in measuring report according to the data of meteorological service. In this research work next physical quantities of weather conditions were fixed: temperature of outside air, outdoor absolute pressure level, humidity level of air. Also the time and data of measuring should be fixed in the report. The best way of research the indoor climate of some certain premise is to measure several physical parameters at the same period of time. It's so because general quantities of indoor climate are quite interrelated between each others. One parameter effects to others. The best way to describe this approval is to consider the equation (2):

$$PV = nRT = \frac{m}{M}RT \qquad (2)$$

This equation describes the ideal gas law and was stated by Emile Clapeyron in 1834. The equation shows interrelation between absolute pressure of gas P, volume of gas V, temperature of gas T. The n is the coefficient which describes the relation between mass m and molar mass of the gas M. R is the Boltzmann constant. This approval (ideal gas low) is quite corrected for description of real gas conditions. So the measurements should be performed at the same conditions and at the same time. Otherwise we get uncorrected results. Because at some certain value of pressure we get some certain values of temperature and volume, at another pressure level we may get other values of temperature and volume. Because of it the measurements in all sport facilities were performed during the 1 hour at the evenings commonly. Description of measurements features for each sport facility presented into further article.

4.3.1 Air-supported structure

Research of indoor climate into air dome is the main goal of this bachelor thesis. Measurements of indoor environment in rest two sport facilities were performed with purpose to compare the indoor climate quality into air dome with indoor climate in other typical sports facilities. This article describes the features of measurements in air supported structure.

The points of samplings were chosen according to recommendation in regulation documents. Also there is one feature of choosing measuring points. The measuring devices shouldn’t prevent or interrupt of sports process – workouts. Thus devices cannot be installed somewhere on the soccer field. Because of it devices were installed on the perimeter of dome close to outer shell of dome. The samplings of all physical parameters were performed during workouts and in the end of day. This is quite main conditions for measurements – to fix the result about indoor climate condition in the worst period of time. This requirement was common for measurements into all sports facilities. Duration of samplings was different for each certain type of measurements but all of them were carried out during one day. Also key indicators of weather condition were fixed into research report while the measurements were performed. It’s quite important thing to know the weather outside of sports facility because it can have direct impact on the final results of research. While the measurements in air dome were carried out the parameters of outside environment had next values:

- ✓ Outside temperature +2 C°
- ✓ Relative humidity - 92 %
- ✓ Precipitation - dry, drizzle

These data should be taken into account when the final results of observations will be calculated and final results will be compared.

The measurements of air temperature in air dome were performed by using three data loggers. This device also records samplings of relative humidity of indoor air. The monitoring both parameters were held during 17 hours from evening to morning. Prior to use data loggers were calibrated according to requirements in regulations documents before using. Measuring points were chosen in different parts of air dome in order to get the data about temperature and relative humidity in wider area of sport facility. These points are 1, 2 and 3. The disposition of measuring points presented at the figure 22.

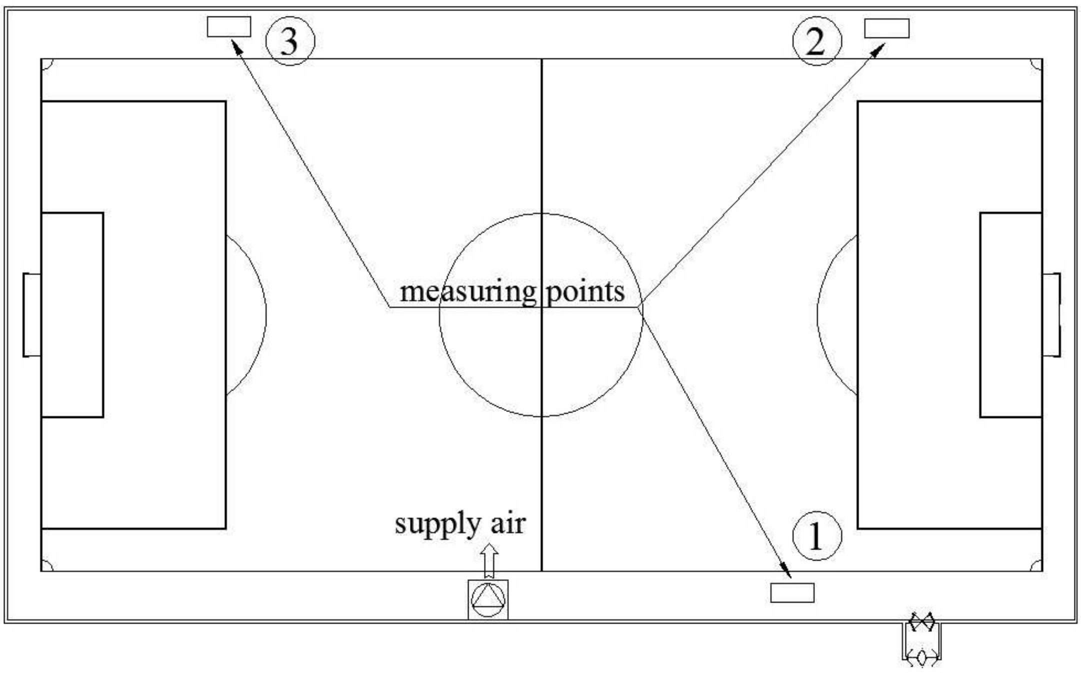

FIGURE 22. Measuring points in air supported structure

The value of air movement was measured by using one device into the same three places where data loggers were placed. The duration of samplings was 3 minutes. All of these points located quite far from flow of supply air. Such disposition of samplings points prevent sudden disturbance of air close to the device's sensor. Thus we can get the mostly correct data of air velocity range into the air dome. The same situation was with measuring carbon dioxide level. Special equipment was fixed at the table for getting samplings of CO2 level. Duration of measurements was about one hour. During this time the device was sampled the CO2 level each minute. All data was recorded and presented at the chapter below.

The measuring of pressure level inside the air dome was performed by using barometer aneroid only. As was written above there is another instrument for measuring indoor air pressure level – micromanometer with two tubes. One open end of tube should be fixed outside of building, the open end of second tube – inside. But the structure of all air domes has one common feature: the envelope of dome insulates indoor space from outdoor space and there is no one openings in envelope of dome as a window for example. The special revolving door like a gateway used for entry to air dome usually. So there are no possible ways to use micromanometer. The next method was applied to define the pressure difference between outdoors and indoors: barometer was installed outside of air dome and, then, inside the dome. The values of measurements were compared between each other and the difference show us the quantity of overpressure inside the air supported structure. The value of overpressure is quite important indicator for air supported structures. The overpressure level is one of the elements of load bearing capacity of air dome. Special supply air devices maintain the pressure inside dome on a certain level. This is one of prerequisites for measuring pressure level in air dome. The second prerequisite of research pressure is influence of overpressure level on overall health of athletes. By measuring of pressure level we can check it and define is the values lay in acceptable range or not.

At the figure 23 presented the overview of measuring point 1 in air dome. The barometer, CO2 probe and data logger were installed at the table. The samplings were taken while workouts occur.

FIGURE 23. Monitoring of indoor climate in air supported structure

4.3.2 Sport hall

The monitoring of indoor climate condition in sport hall was performed during workouts mainly. For measuring of air temperature and humidity level was utilized a data loggers. This device was fixed at the wall of the hall by scotch tape in points 1, 2 and 3. The disposition of these points illustrated at the figure 25 below. The method of fixation devices is shown at the figure 24. The measuring points were chosen in such a way to prevent any external influence or impact on the sensor of the device. For example the data logger was installed quite far from window to prevent influence of radiant temperature due to window surface on the final results of measurements. The monitoring of air temperature and relative humidity level were carried out during the 24-hours.

FIGURE 24. Mounting of data loggers on the walls

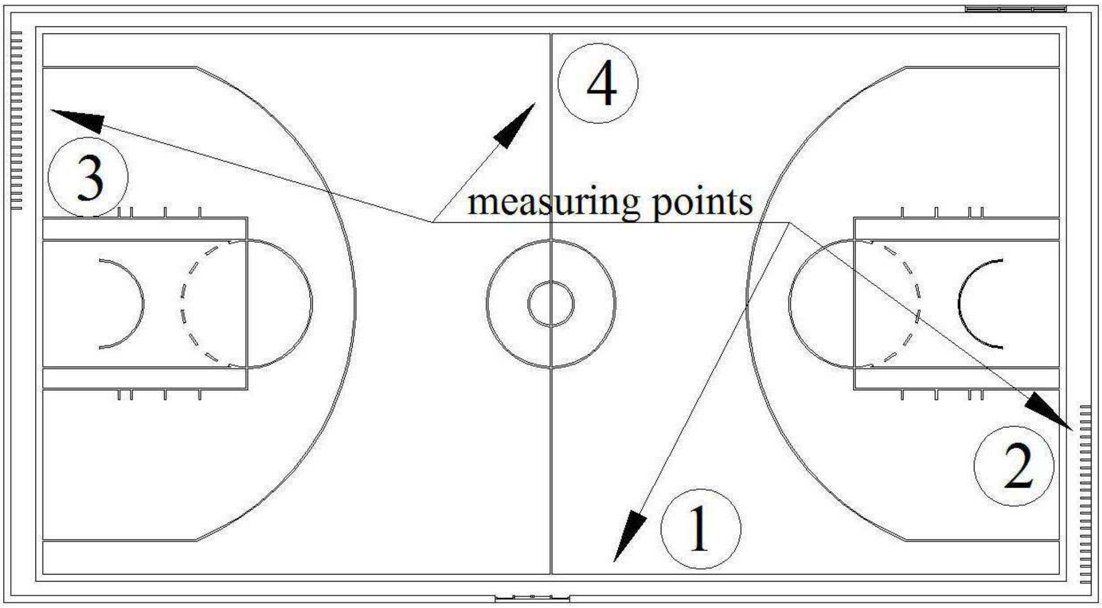

FIGURE 25. Measuring points in sport hall

The measurements of CO2 level were held during the “worst” period of time in terms of indoor climate quality. The worst period of time is at the end of the day and during the workout, when the sport activity on a high level. It should be noted that all windows were closed at time of measuring. All instruments were covered by net of the goal and located in the measuring point 4. The yellow circle at the figure 26 marks it.

FIGURE 26. Covering of instruments by net of goal

The average value of air movement rate was defined by using Swema air 300. This is device with very sensitive probe. The measurements were taken during sports activities in the hall. The duration of samplings was about 3 minutes. The measuring points were chosen on the perimeter of playing zone. The measurements of air movement give us data about average air velocities in several points of sport hall and draft rate also. The process of samplings illustrated at the figure 27 below.

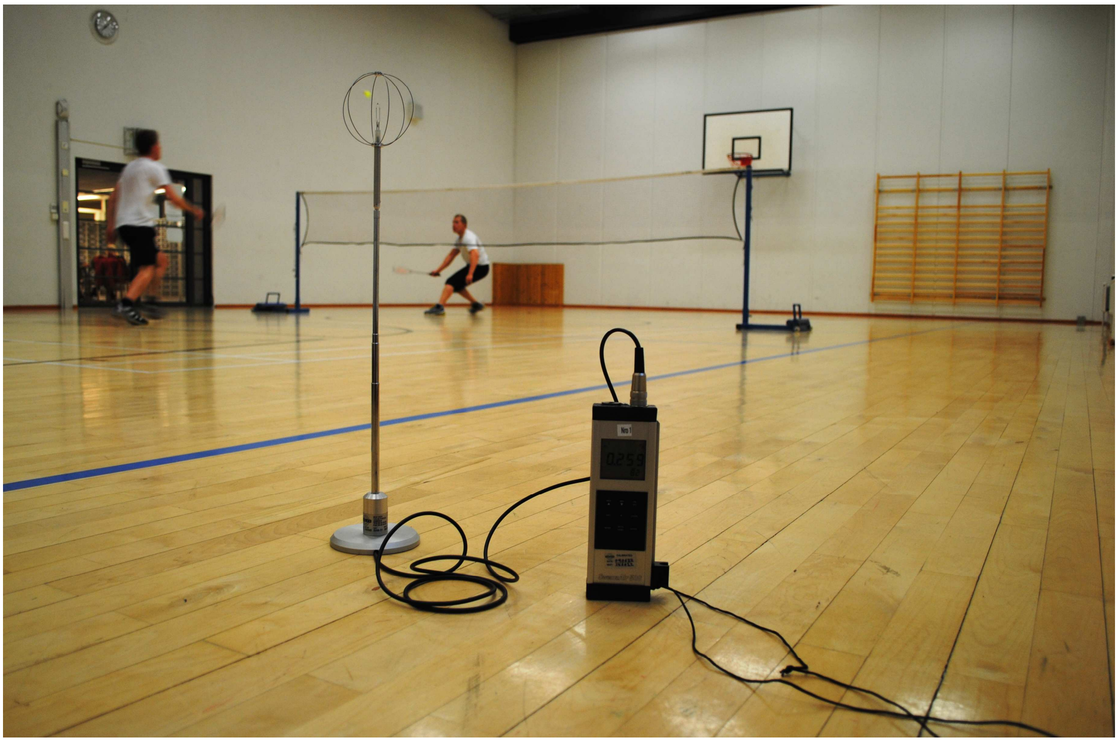

FIGURE 27. Measurement of air movement in sport hall

While the measurements in sport hall were carried out the parameters of outside environment had next values:

- ✓ Outside temperature -1 C°
- ✓ Relative humidity - 87 %
- ✓ Precipitation - dry

4.3.3 Gym

Third object of measurements is gym. The gym consists of two rooms. First room intended for martial arts, yoga and other group sports activities. The second room contains fitness machines and different sports equipment. The measurements were performed in both rooms. Measuring point was located according to the scheme at the figure 28.

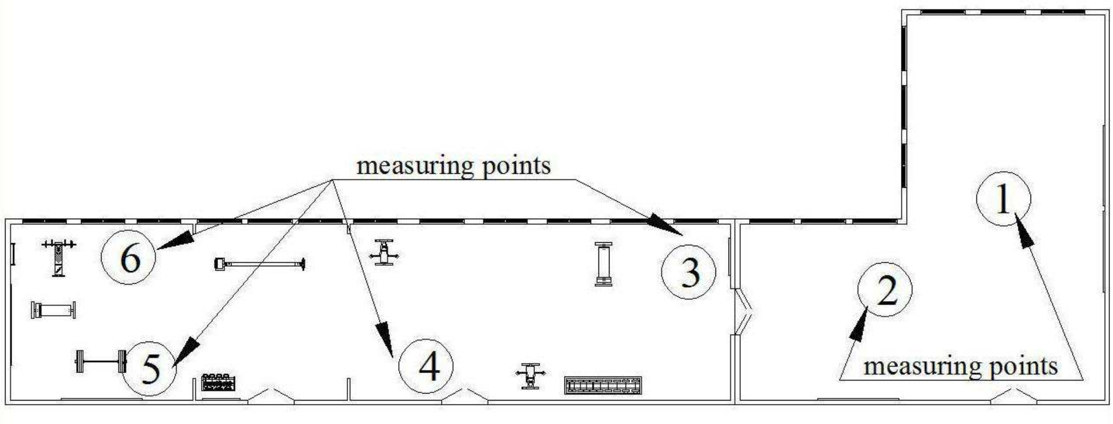

FIGURE 28. Measuring points in gym

The air temperature and humidity level were measured by using data logger. The duration of measurements was about 18 hours. Devices were installed at points 1, 4 and 6. It should be noted that outer walls of both rooms contain windows along the entire length. This fact plays a role in forming of thermal climate in the whole spaces of rooms. Also there is another thing which can affect on the indoor climate. The gym equipped with mechanical ventilation system. Air handled unit located into duct and consist of fan, filter and heat coil inside duct near to air intake. Air intake installed above the window in outer wall of the gym. Supply duct spread fresh air on the whole area of gym. In its own turn the exhaust duct provide the suitable air exchange. The thermometers installed on both sides of air handled unit and show the temperature of intake air (outdoor air) and supply air. The values of air were recorded. While the measurement of indoor climate was carried out, the temperature of intake air was about 10 °C and the temperature of supply air was about 23 °C. The AHU illustrated at the figure 29.


FIGURE 29. Mechanical ventilation in gym

The measurements of carbon dioxide level performed while the athletes were inside the gym. At the same time amount of athletes were recorded in order to control the changes CO2 level according to the number of athletes who were involved in workout. The samplings were taken in measuring points 2 and 5. During the whole measurements the windows were closed. The pressure level was sampled by using special device which allow fixing the difference between outdoor and indoor pressure level. Also sampling of pressure was done by barometer. Both of the result was compared between to each other. The using of both devices allows getting exact values of relative pressure and absolute pressure level.

FIGURE 30. Measurements of pressure difference in gym

Finally, the measuring of air movement rate was performed at the same way as in sport hall. The duration of measuring is 3 minutes. The samplings were taken into few measuring points: 2, 3 and 5. The process illustrated at the figure 31.

FIGURE 31. Measurements of air movements in gym

While the measurements in air dome were carried out the parameters of outside environment had next values:

- ✓ Outside temperature +2 C°
- ✓ Relative humidity - 90 %
- ✓ Precipitation - drizzle

The practical part of research work was completed. All important features of measurements were noted and described. The measurement of different parameters of indoor climate yielded a big amount of results. The results should be handled, corrected and summarized. After that we can evaluate the quality of indoor climate in sport facilities.

5 RESULTS

This chapter contains the description of calculation and processing of the final results of measurements. All measuring data were analyzed and summarized. Based on this it possible to make several conclusions and get the full picture of indoor climate condition in sport facilities. The chapter contains information about finish results and the descriptions of methods of handling these results. All detailed data of measurements were contained in appendixes in reporting tables.

5.1 Calibration and calculation

The article describes the methods of calibration of devices and the ways of handling the getting data. All data which were recorded by devices must be analyzed; all relative calculations must be done. Only after that it possible to make some conclusion about the research works.

All instruments must be calibrated before using. Only in that case it possible to get results which described the condition of indoor climate similar to real situation. Calibration of some devices can be done only by manufacturer of that device. In that case the organization tests the device and compares the data which the device shows with real values. The service of devices should be performed periodically according to the requirements in manual to each certain device. Instruments with very sensitive sensor or probe are serviced by the manufacturer usually. Such type of devices may fix very precise difference in measurand. For example, the Swema air 300 was calibrated by manufacturer before this research work. As a fact of calibration, the manufacturer apply reference document with key values and description of calibration methods - certificate of calibration. Also the calibration allows getting the information about accuracy of samplings of the device. The reference document of Swema air 300 calibration presents in the appendix 1 of the thesis. The second way to calibrate the instruments is to applying some methods of correction the results for each certain kind of measuring devices. Further provides the description of these methods of calibration for each instrument.

The calibration of devices for measuring of carbon dioxide level was done by using special balloons with already known gauge values of carbon dioxide level. One balloon contain 0 ppm of carbon dioxide; the second – 1000 ppm. These balloons were supplied with the main instrument TSI 460. The purpose of these balloons is the calibration of the device. The probe of TSI 460 was connected absolutely hermetically to the first balloon with 0 ppm of carbon dioxide and the samplings were taken. Then the device was connected to the second balloon and the same process was repeated. After that the values from display of instruments were compared to the real gauge values of carbon dioxide level in both balloons. The calibration curve was drawn according to the results of comparison. The graph of calibration illustrated at the figure 32.

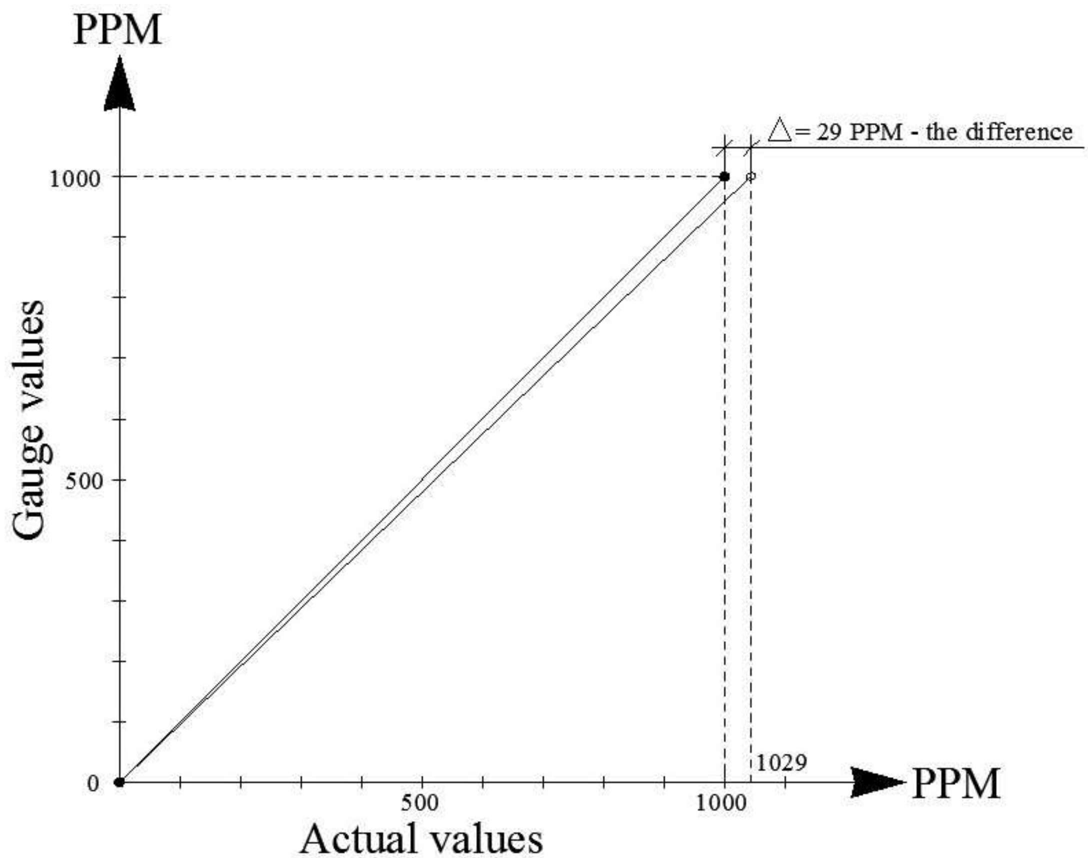

FIGURE 32. The curve of calibration TSI 460

As we can see, the actual readings of instrument a little bit differ from the gauge values. Also the curve describes the next relation: the higher the value of ppm, the bigger deviation of actual data from gauge data. While the real amount ppm of carbon dioxide is 1000 the device shows the 1029 ppm of carbon dioxide. It means that in range from 0 to 1000 ppm the biggest deviation is 29 ppm of carbon dioxide. Almost all results of measuring CO2 level in sports facilities are within this range. In fact the special correction coefficient must be added to all final data after calibration of device. But it should be noted that according to manual of the TSI 460 the accuracy of measurements is ± 3 % of reading or 50 ppm, whichever is higher. The 3 % from 1000 ppm means that the deviation is 30 ppm. It means that the calibration of the devices show that the instruments readings are within the possible range of deviation. So the correction coefficient is not mandatory for applying to final results. All data of measuring carbon dioxide level could be considered as a final result without correction coefficient.

The monitoring of air temperature and relative humidity level were performed by using three data loggers. Sometimes data loggers can show the different readings even if they installed at the same location. The analyzing and summarizing the data from these devices is more complicated without correction of samplings. The way of calibration the data loggers is comparison the readings of devices between each other. For that purpose it's useful to create the table of data. The data loggers were placed at the same measuring point for a one hour. During this period of time data loggers measured the air temperature and relative humidity level once time per each 10 minutes. The samplings were combined in the table 10. The values shown in the table 10 are average for each parameter for one hour of measuring.

TABLE 10. The average values of samplings by data loggers

	Data logger No. 1	**Data logger No. 2**	**Data logger No. 3**
Air temperature, °C	21.7	22.0	21.9
Correction coeff.	+ 0.2	- 0.1	± 0.0
RH, %	41.5	42.3	42.7
Correction coeff.	+ 0.8	± 0.0	- 0.4

The calibration of data loggers allow to get correction coefficient for final data of each instruments. Due to these coefficients the finish results of measuring describe the indoor climate condition quite closer to real situation. The evaluation of indoor climate quality becomes more accurate and correctly.

The article contains description of all key calculations ways which were utilized for handling of measured data. The draft rate was measured by using instruments Swema air 300 which is programmed with certain equation. The equation of DR calculation presents in the standard ISO 7730 and CR 1752 for example. Also for each sport facility the calculation of PMV and PPD indices was performed. The input values for this calculation are clothing, air temperature, activity level of sportsman (metabolic rate), air velocity and relative humidity. Such parameters as air temperature, relative humidity and air velocity were measured by different instruments. Other values were getting according to the appendixes of the standard ISO 7730. For example, in this research work the value of metabolic rate and clothing insulation were chosen according to the typical physical activity of sportsman. This value is equal to 4 met or 232 W/m2. The input value insulation of clothing also was chosen equal for all three sport facilities. For that purpose the insulation of clothing for each certain thing of sport garment were summed in the table 11. All data were given from the table

TABLE 11. The clothing insulation of sport garment

Garment description	**I_{clu}, Clo**	**I_{clu}, $m^2 K/W$**
underwear	0.02	0.003
shorts	0.06	0.009
t-shirts	0.09	0.014
socks	0.02	0.003
Shoes (thin soled)	0.02	0.003
Sum of clothing	**0.21**	**0.032**

As we can see from the table 11, the insulation of clothing of typical sport garment is equal to 0.21 clo. The full equations for calculation of PMV and PPD indices are presents in the standard ISO 7730.

5.2 Air-supported structure

The article contains the final data of measurements and monitoring of indoor climate parameters. All measured data were handled and analyzed. The common way to present the results is to use the graphs and tables. The results of measuring each certain parameter presents separately.

The air temperature and relative humidity are the first indoor climate parameters which were considered. Although the measurement was done in three points, the curve of monitoring illustrates only the data of measuring from first points. Because the monitoring in these points showed that the character of air temperature and relative humidity changes is the same in all three points and in all indoor spaces of dome respectively. It's shown at the figure 33 below. The measuring data in rest two points is expressed by average values which shown at the figures 35.

The key values of air temperature and relative humidity monitoring:

- ✓ Duration of measurement: 17 hours
- ✓ Interval of samplings: 10 minutes
- ✓ No. of measuring point: 1
- ✓ Average value of air temperature: 17.6 °C
- ✓ Minimum of air temperature: 16.6 °C
- ✓ Maximum of air temperature: 20.4 °C
- ✓ Average value of relative humidity: 37 %
- ✓ Minimum of relative humidity: 34.7 %
- ✓ Maximum of relative humidity: 40.8 %
- ✓ Outdoor air temperature: + 2 °C
- ✓ Relative humidity outdoors: 92 %

The curve of air temperature behaviour shows that temperature decreased during the night time. The one possible reason for that decreasing is natural cooling process during the night which impact on the thermal climate due to light structure of outer envelope of the dome – membrane. The second possible reason is that the engineering systems of dome equipped with automatically time relay and all systems switched on the

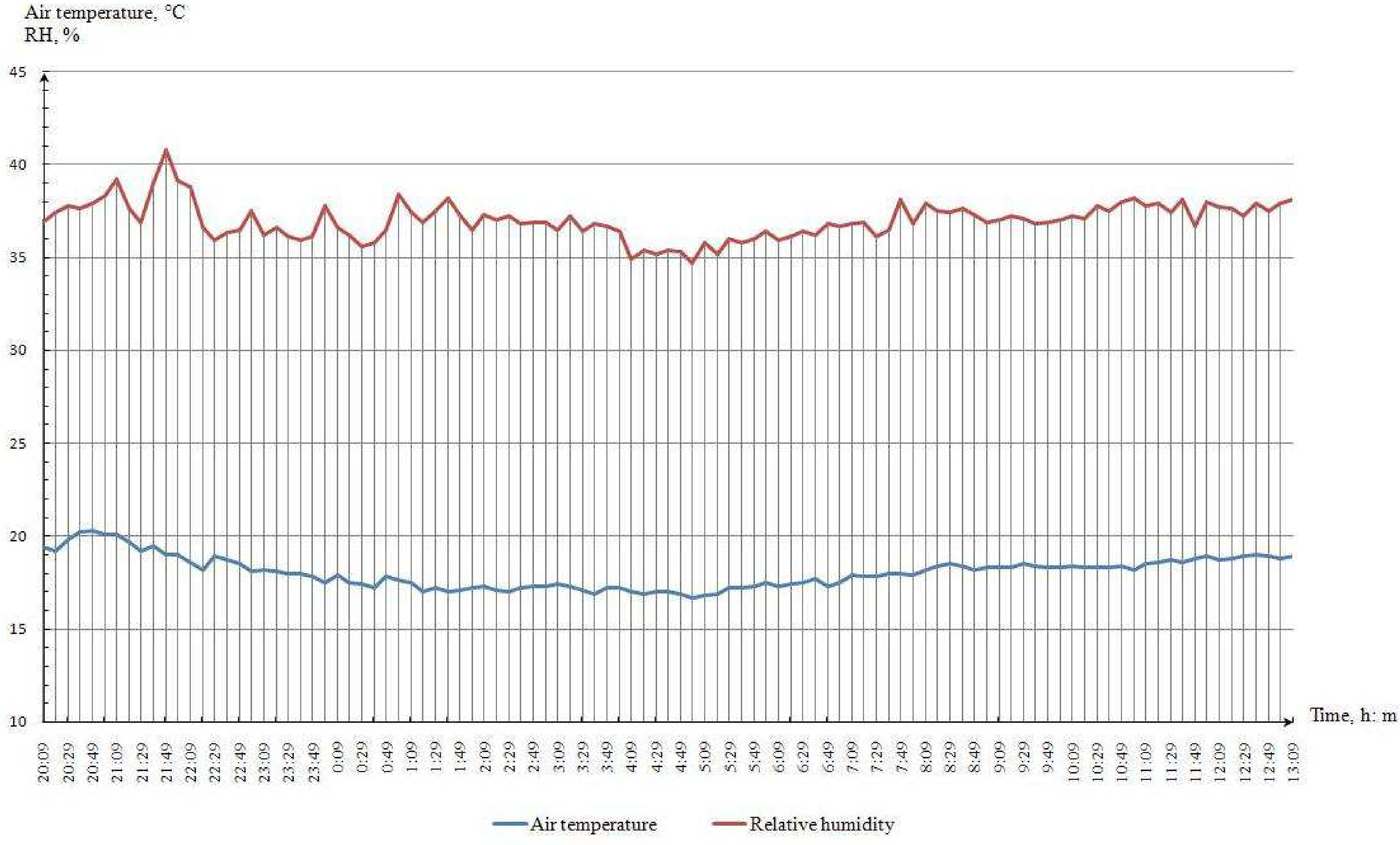

FIGURE 33. The monitoring of air temperature and relative humidity in dome

night mode. This is a typical option of energy efficient system. Also according to temperature curve it possible to suggest that the thermal climate is quite unstable. Although the curve changes quite slowly and smoothly, the amplitude of temperature differences is about 3.8 °C. This range is slightly greater than the value which was given in requirements. The classification of indoor environment requires that the air temperature should be at the same level at least during 80 % of operating time for example /9/. The curve of relative humidity level is a little bit changeable or chaotic at the beginning of monitoring. But then the behaviour of curve became more uniform. The possible reason of curve changes at the beginning is the sportsmen which have workouts at that time. The human is the main source of humidity indoors especial sportsmen which usually sweating during sport activities. One of conclusions of monitoring is that such enclosure as a membrane of air dome can't maintain stability of thermal climate inside.

The second measurement is a carbon dioxide level inside the air supported structure. Result of this measurement expressed by curve. The samplings were taken in single measuring point while the few workouts occur. The number of sportsmen was recorded during the monitoring.

The key values of carbon dioxide level monitoring:

- ✓ Duration of measurement: 1.5 hours
- ✓ Interval of samplings: 1 minute
- ✓ No. of measuring point: 1
- ✓ Average value of carbon dioxide level: 655 ppm
- ✓ Minimum level of carbon dioxide: 605 ppm
- ✓ Maximum level of carbon dioxide: 685 ppm
- ✓ Average number of sportsmen: 29 persons

The behaviour of concentration curve is quite difficult for analyzing. The apparent relation between amount of sportsmen and concentration of carbon dioxide is complicated for detecting. The one of the possible reasons for that is the great volume of the air dome and the small operation area of probe of instrument in comparison with total area of sport facility. At least it takes maybe more time until the sensor of device start

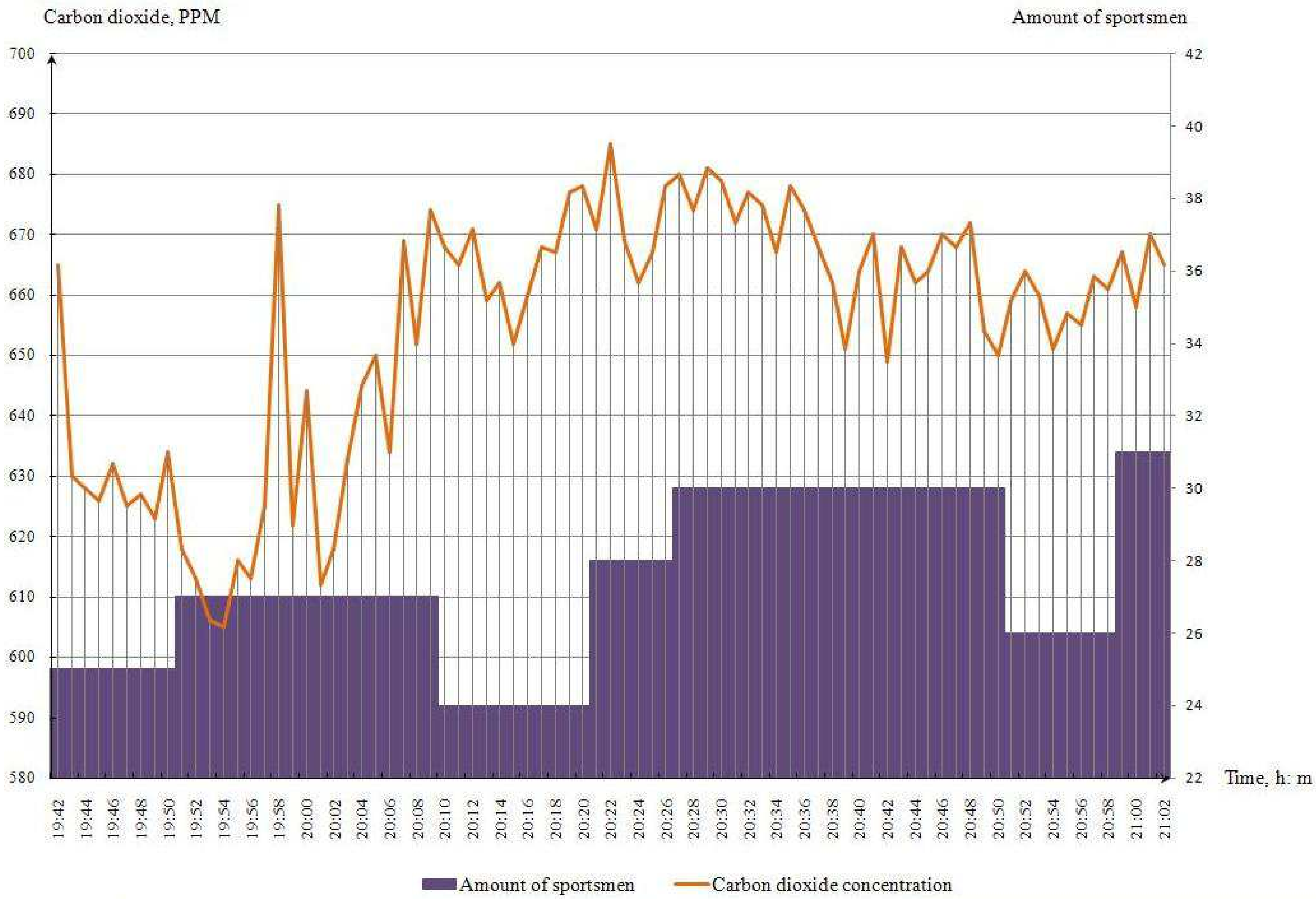

FIGURE 34. The monitoring of carbon dioxide concentration in air supported structure

to detect the impact of amount of sportsmen on the carbon dioxide level. Also it should be noted that the curve changes are sudden and a bit chaotic especially at the beginning of monitoring. Further the range of changes becomes more stability. Also the influence of sudden breathing of somebody who was closer to the probe shouldn't be excluded. But generally the character of curve allows to make a conclusion about average value of carbon dioxide concentration and the range of its fluctuation.

The measurements of air velocities were performed in all three points. The samplings were taken three times in each location. The average value expresses the mean rate of air movement. As was written above the instrument for measuring air velocity can calculate a draught rate also. Also the Swema air can record minimum and maximum values of air velocity during period of sampling. Thus this information allows to make a suggestion about fluctuation of air velocity. The negative minimum values mean that direction of air flow is close to zero. In calculation of average is performed by operating with absolute magnitudes. The results of measuring summarized in the table 12.

TABLE 12. Results of measuring air velocity in dome

No. measuring point	**Air velocity, m/s**			**Draught rate, %**
	min	average	max	
1	0.153	**0.374**	0.593	37.8
2	0.000	**0.268**	0.341	23.2
3	0.000	**0.310**	0.402	24.5

The key values of air movement measuring:

- ✓ Duration of sampling: 3 minutes
- ✓ No. of measuring points: 1, 2 and 3
- ✓ Average value of air velocity: 0.317 m/s
- ✓ Maximum value of air velocity: 0.593 m/s (point No 1)
- ✓ Minimum value of air velocity: 0.000 (point No 2 and 3)
- ✓ Fluctuation of air movement: 0.593 m/s
- ✓ Average value of draught rate: 28.5 %

The results show that the greater air velocity in the point 1, which is close to the entrance revolving door. The higher magnitude of fluctuation also was sampled in first point. Such situation looks logical. Generally the value of air movement in rest parts of dome is quite suitable and the fluctuation of air velocities is stable. The pressure level was measured by using the barometer which expresses only absolute pressure level. The barometer was installed at the table inside the air dome for an hour. The instrument should become to steady state. In that case the barometer shows the correct value. After that the barometer was installed outside of facility for measuring atmospheric pressure. The difference of these values expresses the magnitude of overpressure inside the air dome. Results of measuring are given in the table 13.

TABLE 13. Results of pressure measuring in air dome

Internal pressure level, kPa	101.6 ± 0.05
Outer pressure level, kPa	101.3 ± 0.05
Magnitude of overpressure, kPa	0.3 ± 0.05

The measuring of pressure level show that the magnitude of overpressure inside the air supported structure is about 300 Pa and ± 50 Pa – the accuracy of barometer. The total pressure inside the air dome was 101 600 Pa. Such pressure level was created by air supply system also. It's enough for supporting of enclosure membrane of dome. The all results of measuring were described and analyzed. All data which were obtained during the investigation of air supported structure are summarized and illustrated at the scheme of air dome at the figure 35.

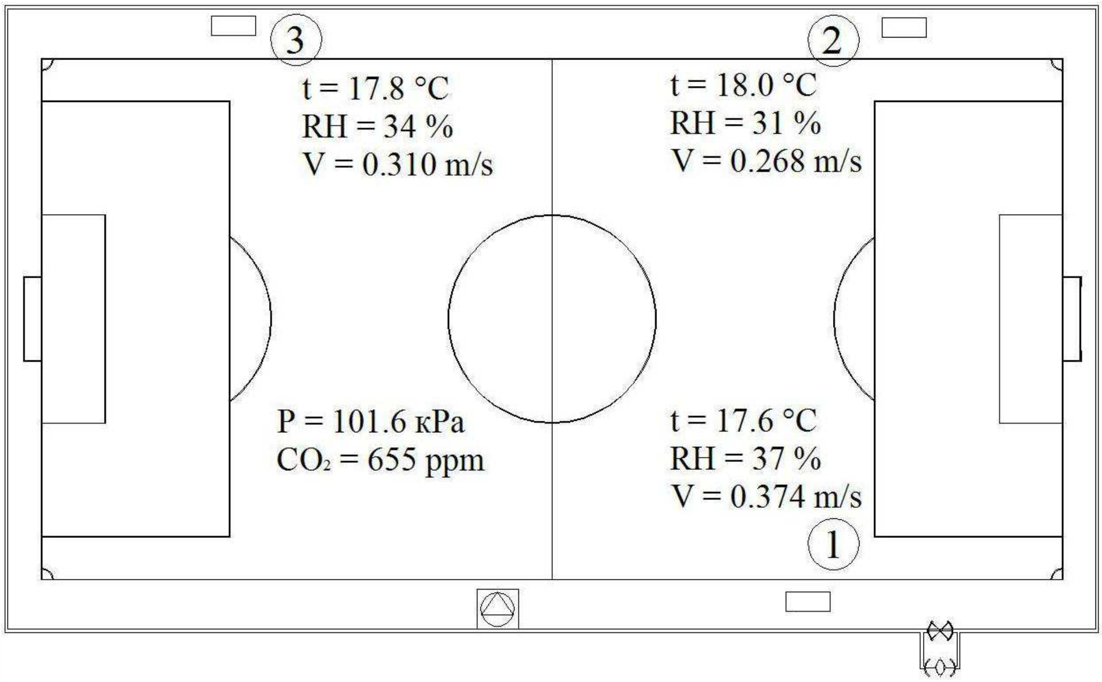

FIGURE 35. Final results of measurements in air dome

The quality of indoor climate is expressed by different parameters and many of these factors were measured and analyzed except two: PMV and PPD indices. These two factors describe the satisfaction of occupants with indoor climate quality. The magnitudes of indices may be calculated according to obtained final result of research. The method of calculation and equations are given in the ISO 7730. But it should be noted that these type of evaluation is more suitable for indoor climate in such premises as offices, classrooms and so on. The PMV and PPD indices were applied as an approximate evaluation of indoor climate in sport facilities. Next values of different parameters were used in calculation of PMV and PPD indices:

- ✓ Clothing insulation: 0.21 clo
- ✓ Air temperature: 17.6 °C
- ✓ Metabolic rate: 4.0 met
- ✓ Air velocity: 0.262 m/s
- ✓ Relative humidity: 37 %

The result of calculation is illustrated on the figure 36.

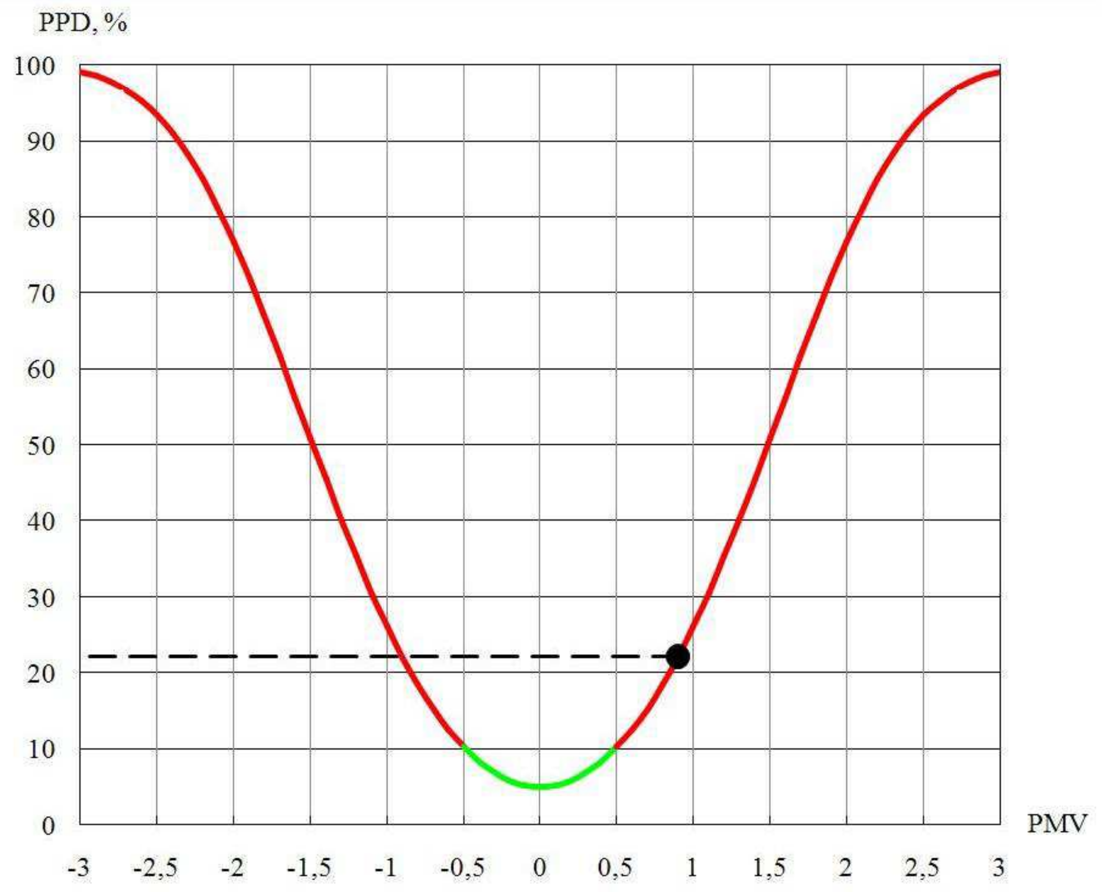

FIGURE 36. PPD and PMV values for air supported structure

According to calculation next values was obtained:

- ✓ PMV = 0.9
- ✓ PPD = 22.1 %

The magnitude of PMV and PPD indices shows that the thermal comfort in air supported structure is quite suitable but not greater. More than 20 % of sportsmen will be dissatisfied with indoor climate. According to the standard CR 1752 the obtained values a little bit low than category C of classification for example. The overall comparison of indoor climate parameters with requirements in regulation documents and guidelines is given in article 5.5.

5.3 Sport hall

The principal of measuring method of air temperature and relative humidity in sport hall is the same which was applying in air dome. The data loggers were installed according to measuring point's disposition which is illustrated at the figure 25. The duration of sampling during 24 hours allow to consider all operating processes which can occur in sport hall. For example, the indoor climate condition during workouts and during night time when engineering system works in economy mode. All key information is given in the list below:

- ✓ Duration of measurement: 24 hours
- ✓ Interval of samplings: 10 minutes
- ✓ No. of measuring point: 3
- ✓ Average value of air temperature: 21.2 °C
- ✓ Minimum of air temperature: 20.5 °C
- ✓ Maximum of air temperature: 21.5 °C
- ✓ Average value of relative humidity: 24.4 %
- ✓ Minimum of relative humidity: 20.8 %
- ✓ Maximum of relative humidity: 26.9 %
- ✓ Outdoor air temperature: - 1 °C
- ✓ Relative humidity outdoors: 87 %

According to sampled data curves of monitoring the air temperature and relative humidity were created. These curves are shown at the figure 37. The average value of air temperature is 21.2 and it suitable according to standards. The range of temperature during the monitoring is about 1 °C and it also quite small changes so the thermal cli-

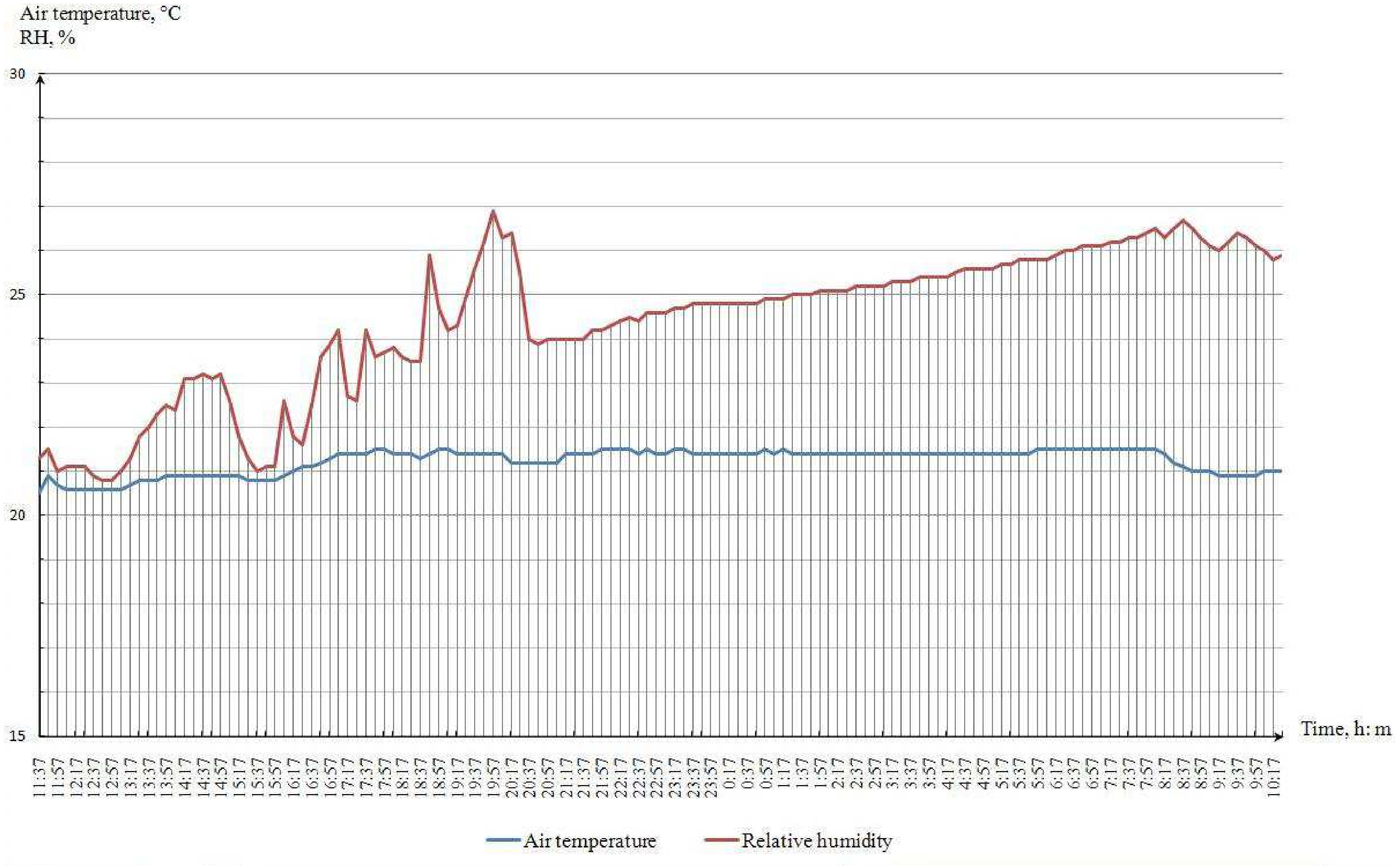

FIGURE 37. The monitoring of air temperature and relative humidity in sport hall

mate is stable in sport hall. Thus the behaviour of temperature curve also looks constantly. Interesting moment is that the magnitude of temperature is lower during the day workouts in contrast with night time where the temperature is higher. The curve of relative humidity looks more unstable especially in the beginning of monitoring. The range of relative humidity is about 6.1 %. The fluctuation can be explained by workouts which were occurring during day and evening. The sportsmen usually sweat at workouts and total amount of water in air increasing. The middle magnitude of relative humidity is quite small as amplitude too. Small fluctuation of humidity in air is testifies about stability state of indoor environment in sport hall. In general the indoor climate is quite dry. Such assumption can be made according to average value of humidity and according to standards.

The measurement of carbon dioxide level was performed while the sport game has occurred in hall. The measuring device was protected from any sudden impact. Thus the probe was installed as close to potential emitters of carbon dioxide as it possible. The main emitters of carbon dioxide in indoor spaces are a human. The overall amount of sportsmen was recorded during the monitoring. It should help to detect the relation between amount of persons inside sport hall and CO_2 level. The key values of carbon dioxide level monitoring in sport hall:

- ✓ Duration of measurement: 3 hours
- ✓ Interval of samplings: 1 minute
- ✓ No. of measuring point: 4
- ✓ Average value of carbon dioxide level: 566 ppm
- ✓ Minimum level of carbon dioxide: 551 ppm
- ✓ Maximum level of carbon dioxide: 594 ppm
- ✓ Average number of sportsmen: 10 persons

The curve of carbon dioxide monitoring is shown at the figure 38. The average level is meeting the requirements of standards. Fluctuation of CO_2 level is laid in suitable range – 28 ppm. The curve of monitoring looks a bit inconstantly. But entirely the line of trend is related to amount of sportsmen except one period of time. This point can be detected by comparison of CO_2 curve and histogram which expresses the amount of sportsmen.

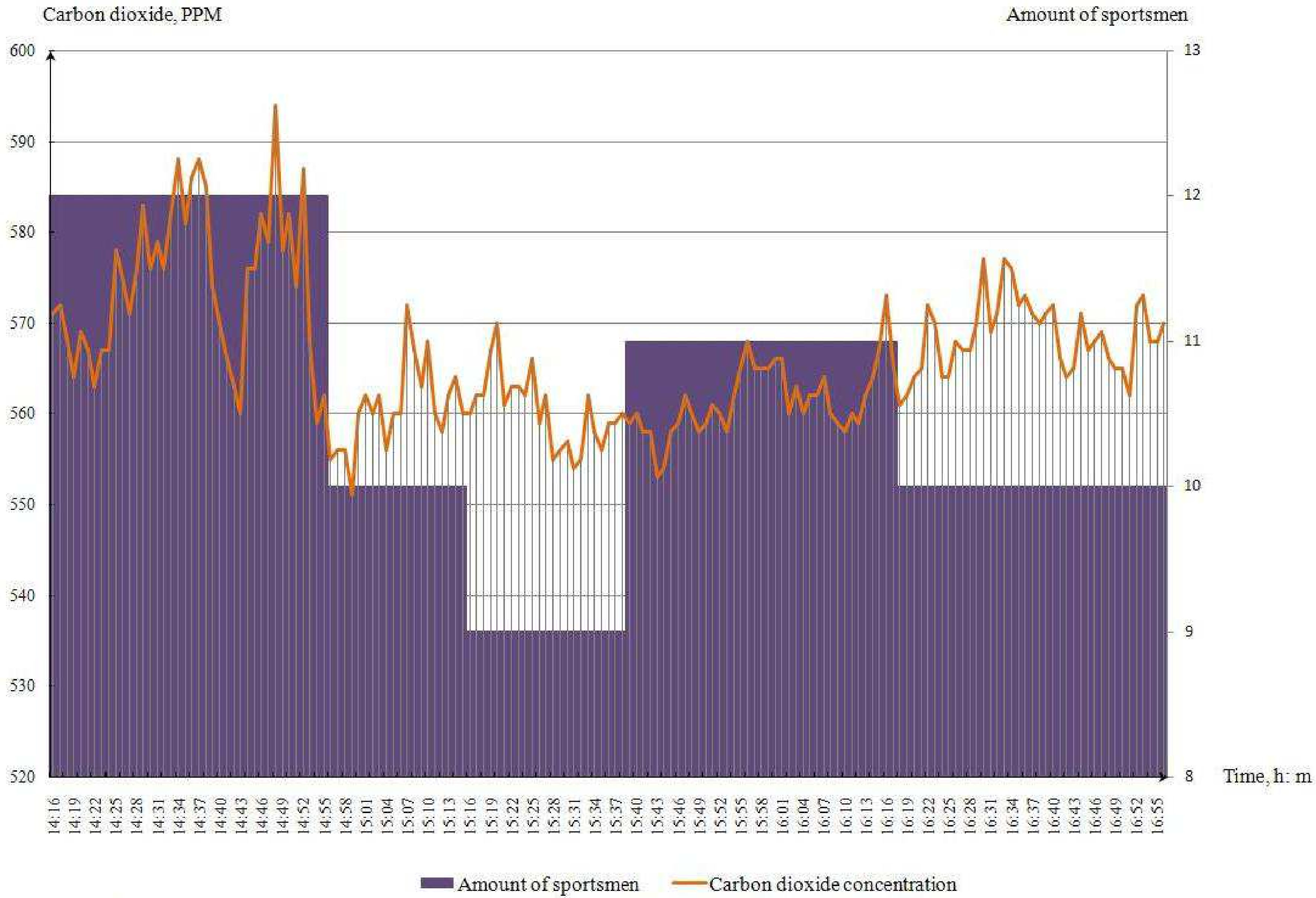

FIGURE 38. The monitoring of carbon dioxide concentration in sport hall

The measuring of air movements was performed close to measuring points 1, 2, 3 and 4. So the air velocities were sampled on the perimeter of game zone of sport hall. All results of measuring given in the table 14.

TABLE 14. Results of measuring air velocity in sport hall

No. measuring point	Air velocity, m/s			Draught rate, %
	min	Average	max	
1	0.000	**0.158**	0.310	19.4
2	0.000	**0.145**	0.357	20.7
3	0.000	**0.118**	0.672	18.1
4	0.118	**0.299**	0.579	40.5

The key values of air movement measuring in sport hall:

- ✓ Duration of sampling: 3 minutes
- ✓ No. of measuring points: 1, 2, 3 and 4
- ✓ Average value of air velocity: 0.180 m/s
- ✓ Maximum value of air velocity: 0.672 m/s (point No 3)
- ✓ Minimum value of air velocity: 0.000 (point No 1-3)
- ✓ Fluctuation of air movement: 0.568 m/s
- ✓ Average value of draught rate: 24.7 %

The measurement shows that greatest average air movement was recorded in the point 4. This point located near to single window in sport hall and such result is predictable. Also the interesting situation was in point 3. The biggest fluctuation may be explained by sudden single air flow (draught) during the sampling. All values of air velocities in sport hall illustrated on the figure 39 according to measuring points. The measuring of air pressure level was done by using micromanometer and barometer. The barometer was installed in the point 4 for an hour. In this point we get the magnitude of internal pressure level. Then barometer was installed outside of sport hall. The micromanometer was used as second instruments for air pressure measuring. The tube was laid through the window. All measuring data is given in the table 15 below.

TABLE 15. Results of pressure measuring in sport hall

Internal pressure level, kPa	101.25
Outer pressure level, kPa	101.3
Difference, kPa	0.05

The difference between outer and indoor pressure levels is about 50 pa. This magnitude is underpressure level inside the sport hall. Final data of measuring illustrated on the plan of sport hall at the figure 39.

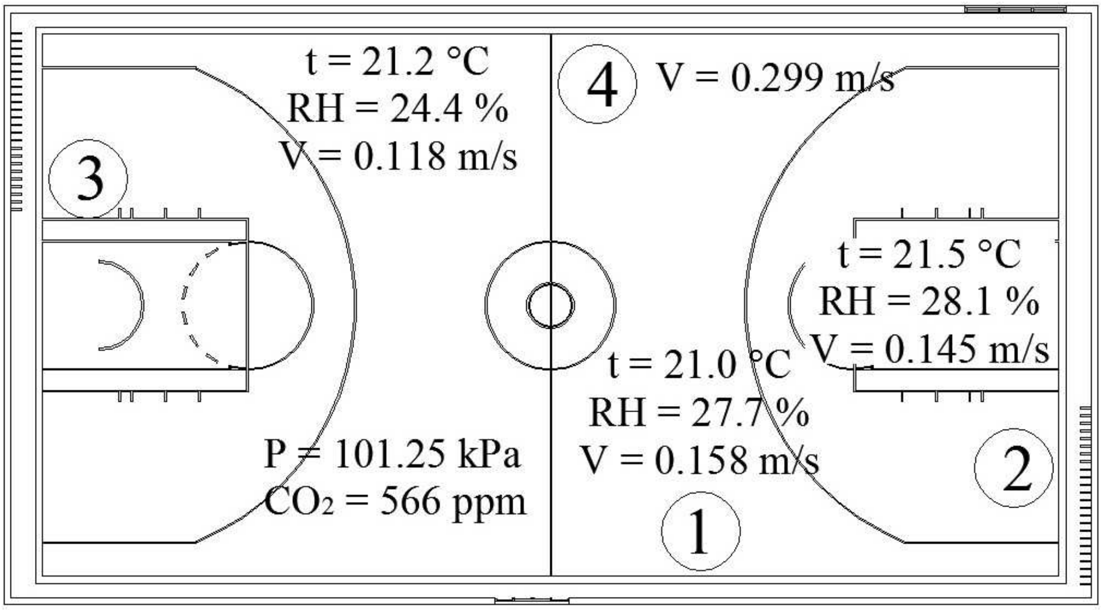

FIGURE 39. Final results of measurements in air dome

For evaluation the indoor climate in sport hall PMV and PPD indices should be calculated. These parameters calculated according to the next input values:

- ✓ Clothing insulation: 0.21 clo
- ✓ Air temperature: 21.2 °C
- ✓ Metabolic rate: 4.0 met
- ✓ Air velocity: 0.299 m/s
- ✓ Relative humidity: 24.4 %

The result of calculation is illustrated on the figure 40.

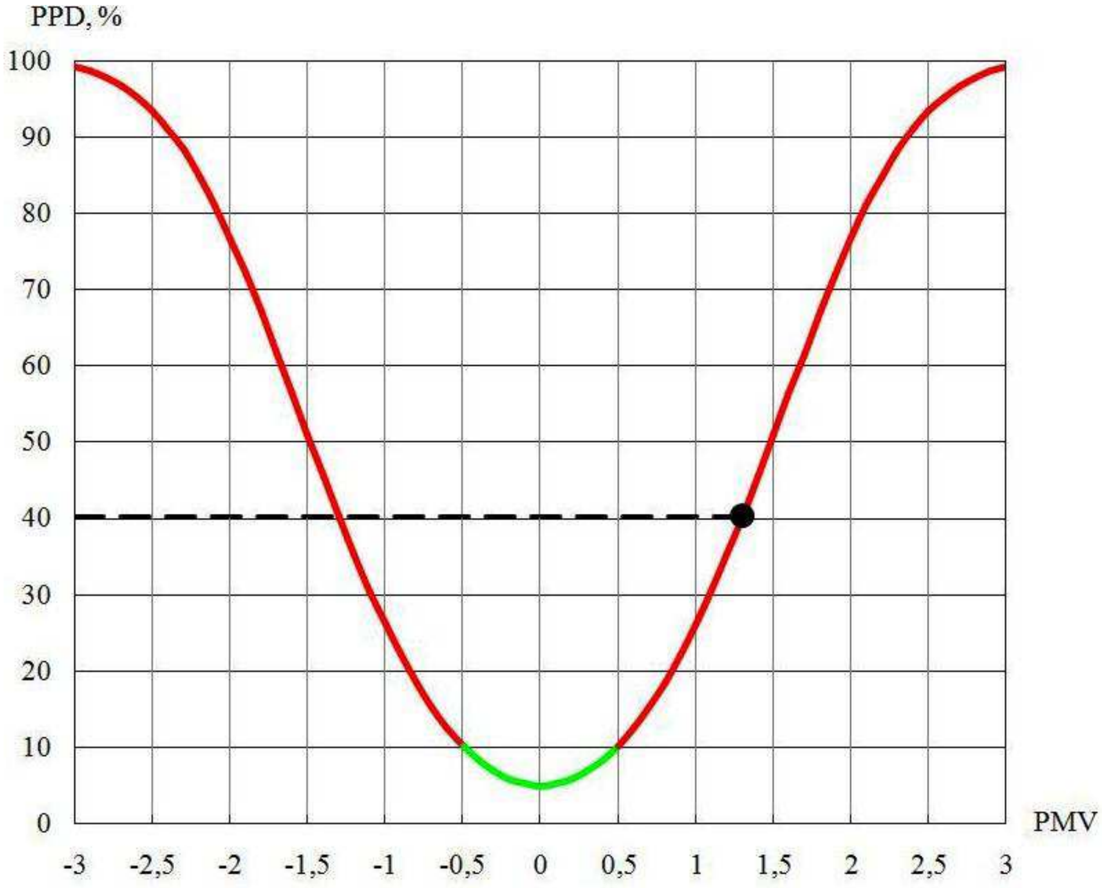

FIGURE 40. PPD and PMV values for sport hall

According to calculation next values was obtained:

- ✓ PMV = 1.3
- ✓ PPD = 40.3 %

The calculation shows that the thermal comfort inside the sport hall isn’t so suitable. Obtained values of PMV and PPD show that there are about 40 % of sportsmen who dissatisfied with thermal climate condition. The one of the main reasons for that is air temperature which is a bit greater. The high activity level of sportsmen and increased metabolic rate require colder thermal condition. Also it should be taken into account that these indices aren’t show the exact situation in such type of buildings as sport facilities. Calculation of these values is based on such factor as activity level which is quite high for sport facilities. This is a one possible reason of that the PMV and PPD indices are pretty approximate for evaluation of indoor climate in sports facilities. The overall comparison of indoor climate parameters with requirements in regulation documents and guidelines is given in article 5.5.

5.4 Gym

The third sport object is gym. This final article contains data of measuring and monitoring of main indoor climate parameters. The measuring of air temperatures and relative humidity was performed in points 1, 3 and 5.

- ✓ Duration of measurement: 21 hours
- ✓ Interval of samplings: 10 minutes
- ✓ No. of measuring point: 3
- ✓ Average value of air temperature: 22.3 °C
- ✓ Minimum of air temperature: 21.8 °C
- ✓ Maximum of air temperature: 23.1 °C
- ✓ Average value of relative humidity: 34.9 %
- ✓ Minimum of relative humidity: 30.8 %
- ✓ Maximum of relative humidity: 42.5 %
- ✓ Outdoor air temperature: + 2 °C
- ✓ Relative humidity outdoors: 90 %

According to the obtained data after monitoring, the curve was created. The curve of monitoring both parameters air temperature and relative humidity is illustrated at the figure 41. As we can see the curve of air temperature is constant during all monitoring. The fluctuation is small and equal to 1.3 °C. The average value is 22.3 °C and it's quite high magnitude for thermal climate especially in sport facilities. Also it should be noted that air temperature higher during the days and lower during the night time. The curve of relative humidity looks chaotic in the beginning of monitoring. The same situation was observed in the previous sport facilities. It may be explained by the day workouts. During the day fluctuation of the curve is greater than during the night when the range is quite small and the curve is more stable. The range of relative humidity is about 11.7 %. The average value is 34.9 %. This magnitude is a little bit high according to the requirements in regulation standards. In general, the overview of curve looks logically: high fluctuation in the day and evenings, then the curve became constant and at the morning when workouts started the fluctuation renewed.

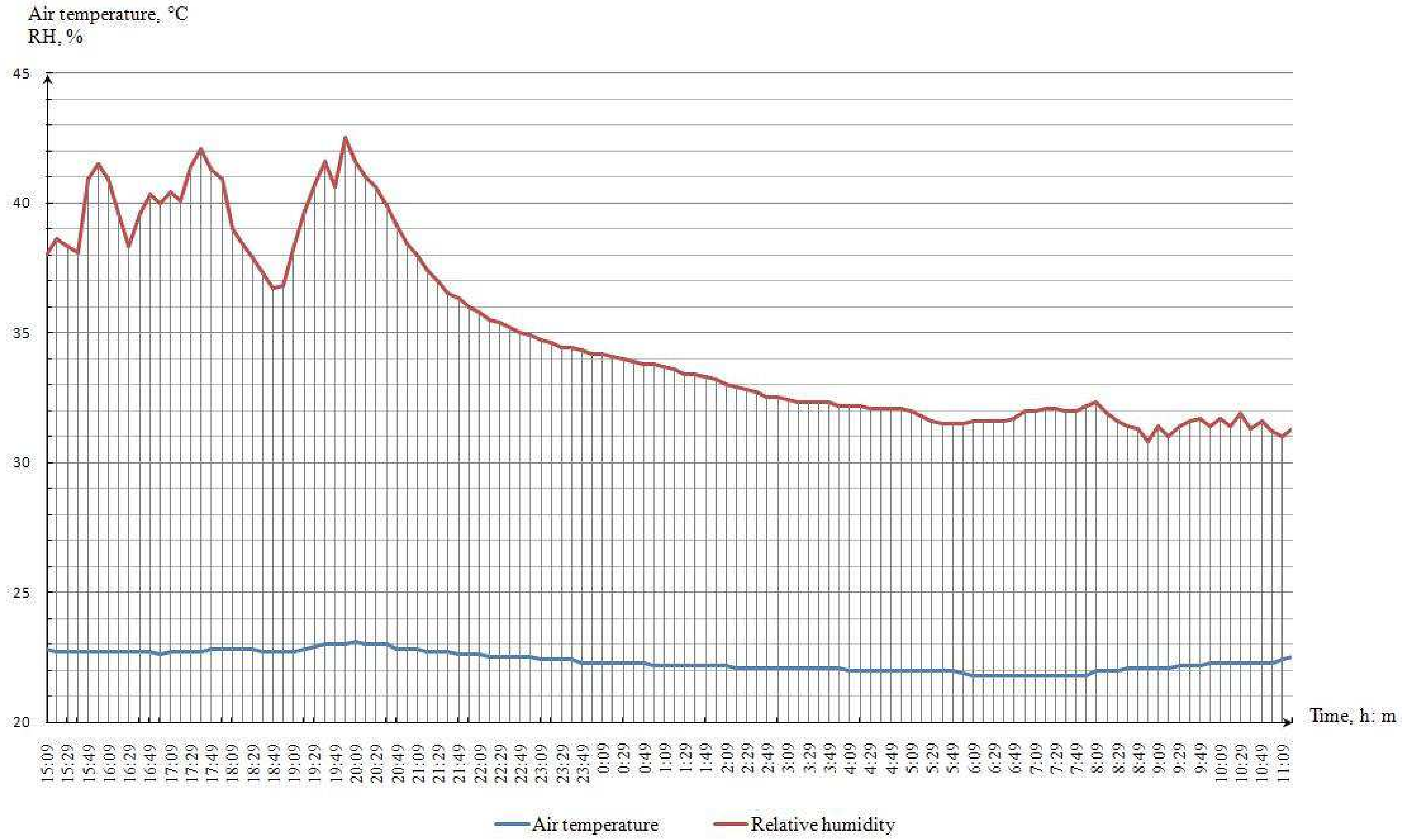

FIGURE 41. The monitoring of air temperature and relative humidity in gym

The measuring of carbon dioxide level was done in the measuring point 3. All obtained data are expressed by curve which is shown at the figure 42. The key values of carbon dioxide level monitoring in sport hall:

- ✓ Duration of measurement: 1 hours
- ✓ Interval of samplings: 1 minute
- ✓ No. of measuring point: 3
- ✓ Average value of carbon dioxide level: 947 ppm
- ✓ Minimum level of carbon dioxide: 697 ppm
- ✓ Maximum level of carbon dioxide: 1225 ppm
- ✓ Average number of sportsmen: 9 persons

The carbon dioxide concentration is a quite high in gym. The average value is equal to 947 ppm. Also the curve behaviour is very unstable and it includes many changes. The range of carbon dioxide level is 528. The highest value in comparison with both others sport facilities. Such big concentration and quick changes of concentration may be explained by a bit small total area and volume of the gym. The measuring was performed during evening workout and there are was about 9 sportsmen inside. The sportsmen are main source of carbon dioxide. In such small volume the each new person can impact on the probe of device faster than if the volume of gym will be bigger. But anyway such concentration may be in premises according to some regulation standards. The measuring of air movements was performed close to measuring points 2, 4 and 6. All results of measuring given in the table 14.

TABLE 16. Results of measuring air velocity in gym

No. measuring point	**Air velocity, m/s**			**Draught rate, %**
	min	Average	max	
2	0.000	**0.106**	0.380	12.5
4	0.000	**0.179**	0.309	15.6
6	0.000	**0.059**	0.136	3.5

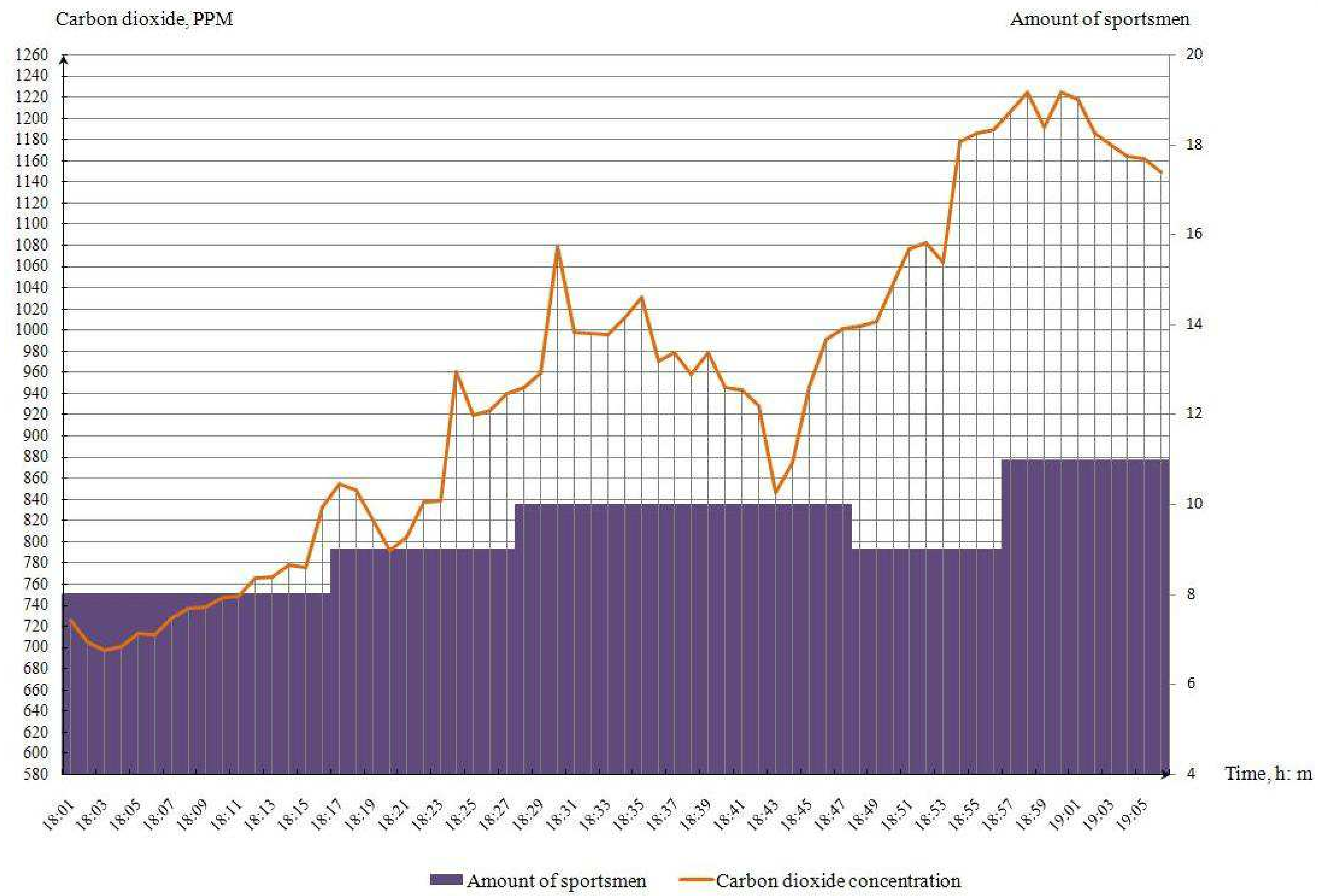

FIGURE 42. The monitoring of carbon dioxide concentration in gym

The key values of air movement measuring in sport hall:

- ✓ Duration of sampling: 3 minutes
- ✓ No. of measuring points: 2, 4 and 6
- ✓ Average value of air velocity: 0.117 m/s
- ✓ Maximum value of air velocity: 0.380 m/s (point No 2)
- ✓ Minimum value of air velocity: 0.000 (in all points)
- ✓ Fluctuation of air movement: 0.273 m/s
- ✓ Average value of draught rate: 10.5 %

The measurement shows that greatest average air movement was recorded in the point 2. This point located near to entrance in gym. According to the obtained data it should be note that the air movement in gym is quite small. The air velocity in the gym is lowest in comparison with other sport objects. All values of air movements in sport hall illustrated on the figure 43 according to measuring points. The pressure level inside the gym was measured by using both instruments: barometer and micromanometer. The data of measurements are given in the table 17.

TABLE 17. Results of pressure measuring in gym

Internal pressure level, kPa	101.4
Outer pressure level, kPa	101.4
Difference, kPa	0.00

The pressure level inside the gym is almost equal to atmospheric pressure level outdoors. The final result of measurements illustrated on the plan of gym at the figure 43.

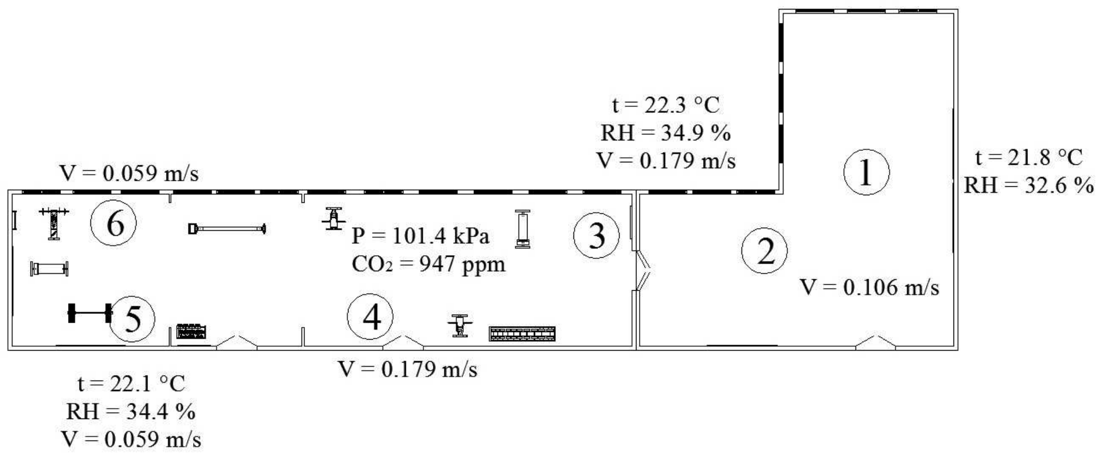

FIGURE 43. Final results of measurements in gym

For evaluation the indoor climate in gym PMV and PPD indices should be calculated. These parameters calculated according to the next input values:

- ✓ Clothing insulation: 0.21 clo
- ✓ Air temperature: 22.3 °C
- ✓ Metabolic rate: 4.0 met
- ✓ Air velocity: 0.179 m/s
- ✓ Relative humidity: 34.9 %

The result of calculation is illustrated on the figure 44.

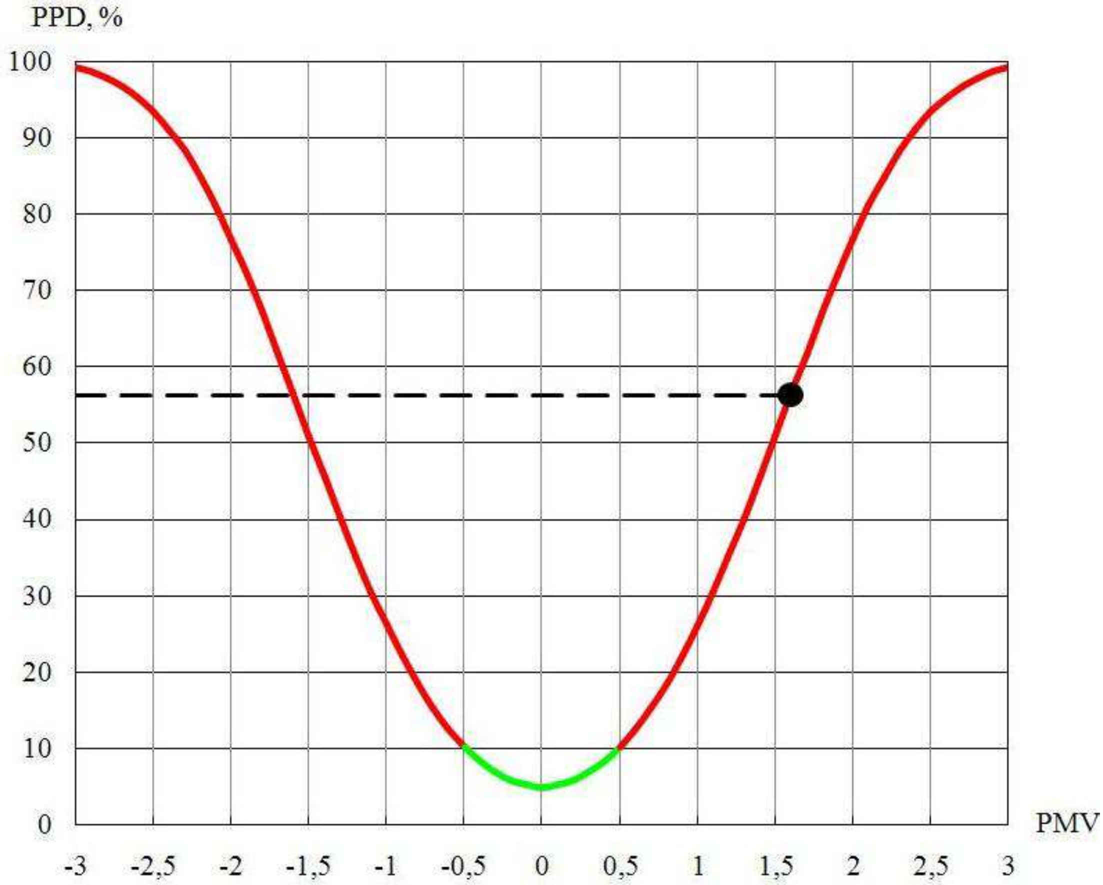

FIGURE 44. PPD and PMV values for gym

According to calculation next values was obtained:

- ✓ PMV = + 1.6
- ✓ PPD = 56.3 %

Such big amount of dissatisfied persons shows that the temperature in sport facilities should be lower at the level at least about 18-19 °C. Otherwise the condition of indoor climate causes discomfort of the sportsmen. The overall comparison of indoor climate parameters with requirements in regulation documents and guidelines is given in article 5.5.

5.5 Comparison

This article contains report of all final measuring data in three researched sport facilities. Obtained data was compared with mandatory standards and most significantly guidelines. These documents are: D2, Classification of indoor environment and ISO 7730. Also the set of requirements which was developed based on other documents presented in comparison. In case when there are several values for different measuring point, the worst value is used. Also the comparison of indoor climate quality was performed between all sport facilities. The result of comparison was given in few tables below. All cells can be marks by three colours: red, yellow and green. The red colour means that this value does not meet the requirements of that standard which is compared. Yellow colour means that the values almost correct according to the standard but not entirely. The green colour expresses the full conformity with requirements of regulation document.

- ✓ (red) - does not meet the requirement
- ✓ (yellow) - almost meets the requirements
- ✓ (green) - meets the requirements

TABLE 18. Results of measuring in air dome. Comparison with standards

	T, °C	RH, %	CO_2, ppm	V, m/s	P, pa	PMV	PPD, %
	17.6	37	655	0.317	101.6	+ 0.9	22.1
D2	18	20-45	≤ 1200	≤ 0.3	101.3	-	-
Classification	21.0,S3	≥ 25,S1	≤750,S1	≤ 0.2,S3	-	-	-
ISO 7730	21±3.5,C	-	-	≤ 0.2,C	-	<0.7,C	<15,C
Extra	18±0.5	32±0.5	≤ 350	≤ 0.14	101.3	< 0.2	< 6

Comparison shows that the indoor climate quality in air domes almost comply with requirements D2. All parameters meet necessary values except air velocity which is a little bit higher. Also it should be noted that the air pressure level is greater than it required. But the air dome is supported by overpressure level inside the dome. This pressure pumps by supply ventilation system. Thus the a bit high values of pressure level and air movements look quite logical. Relative humidity and carbon dioxide level even corresponds to category S1 of classification. The indoor climate quality in air dome entirely is suitable for performing workouts and sport competition. In comparison with extra requirements only single parameter meet the suitable value – air temperature. According to high activity level of sportsmen this magnitude of temperature is much suitable.

TABLE 19. Result of measuring in sport hall. Comparison with standards

	T, °C	RH, %	CO_2, ppm	V, m/s	P, pa	PMV	PPD, %
	21.2	24.4	566	0.180	101.25	+ 1.3	40.3
D2	18	20-45	≤ 1200	≤ 0.3	101.3	-	-
Classification	21.0,S3	≥ 25,S1	≤750,S1	≤ 0.2,S3	-	-	-
ISO 7730	21±1.0,A	-	-	≤ 0.2,C	-	<0.7,C	<15,C
Extra	18±0.5	32±0.5	≤ 350	≤ 0.14	101.3	< 0.2	< 6

In sport hall almost all parameters meets the requirements of D2. But the value of air temperature is more then it needed. The high PPD index may be explained due to this fact. The best values are carbon dioxide level – category S1; air movements – S3 and C. So, the indoor climate quality is quite suitable for performing of workouts according to all parameters except temperature. The sport hall is equipped with mechanical ventilation system and may be the heating coil of AHU should be adjusted on the lower air temperature. In this case the percent of dissatisfied persons should decrease. Also the parameters of indoor environment do not comply with extra requirements except pressure level.

TABLE 20. Result of measuring in gym. Comparison with standards

	T, °C	RH, %	CO_2, ppm	V, m/s	P, pa	PMV	PPD, %
	22.3	34.9	947	0.179	101.4	+ 1.6	56.3
D2	18	20-45	≤ 1200	≤ 0.3	101.3	-	-
Classification	21.0,S3	≥ 25,S1	≤1200,S3	≤ 0.17,S2	-	-	-
ISO 7730	21±3.5,B	-	-	≤ 0.17,B	-	<0.7,C	<15,C
Extra	18±0.5	32±0.5	≤ 350	≤ 0.14	101.3	< 0.2	< 6

The almost all parameters of indoor environment in gym meet the requirements of D2 except air temperature. This value is a higher than it required. It is a possible reason for great amount of dissatisfied persons according to the PPD. The carbon dioxide level complies with D2 but according to classification it's the category S2. The relative humidity meets the extra requirement. Air movement corresponds with categories S2 and B of classification and ISO. The indoor environment of gym is suitable but the temperature should be lower. The way of decision is may be the same as in sport hall – adjusting of heating coil. The second way is installing the air conditioning system. It may be cooling coil which mounted into air ventilation duct. Thus the supply air will assimilate the extra heat in the gym.

TABLE 21. Final comparison of all sport facilities

	Air dome	Sport hall	Gym
T, °C	17.6	21.2	22.3
RH, %	37	24.4	34.9
CO_2, ppm	655	566	947
V, m/s	0.317	0.180	0.179
P, pa	101.6	101.25	101.4
PMV	+ 0.9	+ 1.3	+ 1.6
PPD, %	22.1	40.3	56.3

Final data of measuring in all three sport facilities were compared and the result of comparison is given in the table 21 above. According to that comparison it's possible to make few conclusions. The colours in cells were utilized for marking the best value and the less suitable. The best air temperature for performing of workouts which include high physical activity exercises is in air dome. And even in that case the indices of PMV and PPD in air dome are not corresponding to requirements in ISO 7730. The relative humidity level is better in the gym. In air dome this parameter also not too high. The lowest magnitude of RH was sampled in sport hall. The air inside hall is a bit dry. One of the decisions of this problem may be the installing humidifier in AHU. It helps to increase the relative humidity up to suitable value. The lowest level of carbon dioxide was measured in sport hall and the greatest – in the gym. It means that an indoor space of gym not contain enough fresh air. The possible way to solve the problem is to increase the air flow rate in the gym. The speed of air movement is suitable for gym and sport hall. The greatest magnitude was obtained in air dome. Possible reason of that is special function of air inside the dome which also is a part of load bearing system in contrast with other two sport facilities. The measurements of pressure level show that the internal pressure in hall and gym is almost equal to atmospheric pressure. In air dome overpressure is about 300 pa. In fact it's not so high value which can be felling by occupants in comparison with atmospheric pressure. The PPD and PMV indexes show the quality of thermal climate in researched objects. The lowest level of dissatisfied person is in air dome and the highest - in gym.

The comparison shows that all three sport facilities have quite suitable indoor climate condition for performing workouts and sport competition. The best situation was observed in air dome from thermal climate point of view. Also were performed measuring and comparison of getting data show that air supported structure can be considered as full function sport facility.

6 DISCUSSION

In this thesis the research of indoor climate conditions in three sport facilities was done. All obtained data were handled and analyzed. The results of measuring allow to make a few conclusions about indoor climate quality in all investigated objects.

This research shows that the temperatures in sport facilities should be design in relation to expected activity level of sportsmen. In that case the percent of sportsmen who will be satisfied with indoor climate will increase. All sport facilities should be equipped with engineering systems which can control and maintain the suitable condition of indoor environment.

The main conclusion is that quality of indoor climate in air supported structure meets the mandatory requirements. Such kind of sport facility provides all suitable condition for performing of sport competition and workouts. The air domes can be considering as alterative of ordinary sport centres and buildings. Such advantages as low cost of construction and good indoor environment condition make this type of structure the quite perspective sport facility.

7 CONCLUSION

Suitable quality indoor environment contributes to good feeling of sportsmen and their high productivity on workouts. The decent quality of indoor climate allows sportsmen to achieve the high sport results. The measurements of indoor climate quality show that main parameters of indoor climate lain in a suitable range. The air supported structure can be considered as an alternative type of sport facilities.

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APPENDIX 1

Certificate no: 2319506

Calibration Certificate

Adjustment and calibration of a comfort probe SWA 01

Calibration results:

S/N: 362219
Manufact. date: 1996-05-20
Required Software version: 1.54
Required Hardware version: 1.05

Cal. date: 2012-11-14
Cal. setup: SWEMA
Next cal. date: 2013-05-14
Cal. cond.: 1015 hPa 33 %RH

True val.	Read val.	Corr
7.0 cm/s	8.6 cm/s	-1.6
10.0 cm/s	10.3 cm/s	-0.3
15.0 cm/s	15.2 cm/s	-0.2
25.0 cm/s	24.0 cm/s	1.0
40.0 cm/s	38.4 cm/s	1.6
60.0 cm/s	58.5 cm/s	1.5
80.0 cm/s	78.7 cm/s	1.3
100.0 cm/s	100.1 cm/s	-0.1
(At 1013 hPa)		
22.2 dgC	22.2 dgC	0.0

Calibrated by

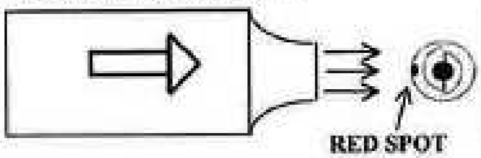
Pernilla Håkansson

SWEMA

Uncertainty of measurement:
Velocity
0,07-0,50 m/s = ± 0,02 m/s.
0,50-1,00 m/s = ± 0,03 m/s
Temperature ±0,3°C
Coverage probability 95%
Instrument uncertainty – see manual

Measuring method:
Calibration in a free air stream.

The sensors position in the Air stream:
Horizontal with the red spot towards the air stream.



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